19. *The* Moffat Series. By Charles Lapworth, Esq., F.G.S.

(Read Nov. 21st, 1877.)

[Plates XI.–XIII.]

Contents.

Introduction.

§ I. *General characters of the Lower Silurian Rocks of the south of Scotland.*

No single geographical region in Britain is more clearly defined physically than the broad tableland known as the Southern Highlands or Uplands of Scotland. Cut off abruptly from the north of England by the shallow inlet of the Solway and the mountain-wall of the Cheviots, and from the main mass of Scotland by the great central valley of Lanark and Midlothian, it stretches like a vast zone across the entire breadth of the island from sea to sea. Occasionally some of its higher points are sufficiently grouped together to be classed popularly under a common title, such as the Moorfoots, Lowthers, and Lammermuirs; but the region, as a whole, may best be described as a rolling sea of broad rounded hills and deep narrow valleys. The only level spots occur along the banks of its few really important rivers, where their lower valleys expand into the long fertile reaches of which the Merse, Nithsdale, and Annandale are the most familiar examples. The more elevated areas, which rarely exceed 2000 feet in height, show here and there strips of peat moss or heathery moor-land. Nowhere, however, do we meet with the crag, cliff, and rocky ground of the Northern Highlands, but hill and dale are clothed alike in a universal mantle of soft green turf. The district is consequently preeminently pastoral, agriculture being almost entirely restricted to the low-lying, open dales.

The rocky floor of the whole of the Southern Uplands is formed of strata of Silurian age. Buried once, either wholly or in part, beneath portions of the Old Red Sandstone, Carboniferous, and Permian, these ancient deposits have again been bared to the action of the elements, which have carved them into that chaos of mountain and valley they now present. The largest surviving fragments of these later formations are the Red and Yellow Sandstones of the valley of the Tweed, and the Carboniferous and Permian rocks of the basin of the Solway. The remainder are mere local patches, scattered along the lines of the chief river-valleys.

Making exception of the narrow belts of altered strata that surround the granitic bosses of Kircudbright and Dumfries, these South-Scottish Silurians are as little metamorphosed as the equivalent deposits of Wales and the West of England. It might therefore be expected that the task of unravelling the physical and zoological succession among them would be correspondingly simple and easy. Unfortunately, however, such is far from being the case. Everywhere possessed of an accountable similarity in their lithological characters, totally destitute of fossils except in a few isolated localities, and, above all, thrown into the most violent folds and contortions, these ancient strata have been shunned by the majority of Silurian geologists, and their sequence has been very differently interpreted by the few who have hitherto examined them.

Of the extraordinary corrugations into which the whole of the South-Scottish Silurians are thrown it is needless to attempt any

description. The rugged cliffs of the Berwickshire coast, where these convoluted rocks frown over the North Sea, have been familiar to geologists since the days of Hutton and Hall. In the inland districts we meet upon every traverse an endless succession of strata dipping constantly in the same general direction, and presenting us with the fallacious appearance of an almost interminable thickness of similar deposits.

The dominant rock of the Southern Uplands is a gritty or coarse-grained greywacke, sometimes grey or green, at other times of a deep purple colour. It is associated with beds of fissile flagstone of similar tints, which either alternate with the greywackes or occur alone in zones of great thickness. These two types of rock everywhere preponderate, and usually prevail to the exclusion of every thing else. Occasionally, however, they are relieved by masses of pebbly conglomerate, breccias, or boulder-beds; but these are very variable in character and local in occurrence.

Excluding from our present consideration the strata recognized as being unequivocally of Upper Silurian age, it is in one district only that the beds of this wide-spreading rock-group approximate in their general characters to the type familiar to us in the classic ground of Siluria. On the west coast, in the neighbourhood of the town of Girvan, limestones, shelly sandstones, and mudstones yield fossils in extraordinary profusion, and, both mineralogically and palæontologically, remind us strongly of those of the most prolific areas of Wales and Shropshire.

A fauna similar in its broader features to that afforded by the Girvan beds, but far inferior in richness and variety, characterizes the calcareous zones in the conglomerates and breccias of Peebles, Lanark, and Dumfries.

A totally distinct group of fossils, and one hitherto regarded as of little geological significance, occurs in certain beds of black carbonaceous shales and mudstones, which, in many districts, occupy long lenticular or boat-shaped areas in the great mass of barren greywacke. These peculiar beds appear quite unexpectedly and as suddenly disappear; but, when laid down upon the map, they are seen to form extended moniliform lines, often many miles in length. They are found at intervals throughout the northern half of the Uplands, from the Irish Channel to the North Sea, and everywhere swarm with Graptolites in extraordinary profusion.

The striking mineralogical features of these black bands, their prolific fauna, and their great longitudinal extent, where for thousands of square miles no other continuous stratum, separable either by lithological or palæontological characters, relieves the wearisome monotony of the interminable greywackes, soon convince the geologist that it is by their aid alone that he can ever hope successfully to unravel the more than ordinary complexity of the South-Scottish succession.

In seeking to elucidate the geological structure of the Southern Uplands, these Graptolitiferous strata naturally claim our first attention. It is impossible to clear up all the difficulties in which they are enshrouded within the limits of a single memoir. In the present

paper I shall therefore restrict myself to the enumeration and discussion of such facts regarding their physical and zoological relationships as may be gathered within the single area where they are most perfectly exhibited, and which may conveniently be denominated the Moffat district.

§ II. *General Characters of the Strata of the Moffat District.* (Plate XI.)

The district included under this title is a rectangular area about 25 miles in length and 8 miles in average diameter, lying almost in the geographical centre of the South-Scottish Silurians. A small portion of the northern half of the area is included in Peeblesshire; the remainder is almost equally divided between the two adjacent counties of Selkirk and Dumfries, the line of demarcation between them running in an irregular curve transversely through its centre.

As a whole, the district may best be considered as embracing that portion of the rolling tableland of South Scotland lying immediately to the north-east of the upper reaches of the fertile vale of the Annan, which, roughly speaking, forms its abrupt western boundary. In every other direction it merges imperceptibly into the sea of rounded heights and hollows that constitute the Southern Uplands. The county boundary already referred to marks the position of the watershed between the head waters of the streams draining into the Irish Sea and those which flow into the German Ocean. This ridge includes the most elevated ground in the south of Scotland, its culminating points, White Combe, Hartfell, &c., exceeding 2600 feet in height. The burns that descend its northern slope unite to form the Tweed and its tributaries, the Yarrow and the Ettrick; those to the south are all feeders of the Annan. These numerous mountain-streams have eroded the ancient plateau into a perfect maze of narrow valleys, many of which, especially those of Blackshope, Carrifran, Gameshope, and the Talla, are bounded by abrupt or precipitous cliffs, and afford striking examples of upland scenery.

The district is cleft longitudinally through its centre, from end to end, by a deep narrow valley, along which passes the highway from Selkirk to Dumfries, forming the only means of intercommunication between its sparsely scattered inhabitants. The western half of this hollow is constituted by the picturesque pass of Moffatdale, which, bounded on both sides by a line of bold heights, runs in a perfectly straight line ten miles in length from the Annan to the watershed at Birkhill. To the east the hollow is continued by the tortuous gorge of the infant Yarrow; this, widening as it descends, embosoms the lonely lake of St. Mary's, and ultimately passes out of the district into the cultivated haughs of the more populous area of Ettrick Forest.

The lowlying flats of Annandale are formed of the relics of Permian deposits; but all the upland portions of the Moffat district are carved out of the grey, intractable Silurian grits and flagstones already so frequently referred to. Beyond a clearly marked ten-

dency in these rocks to arrange themselves in broader and broader zones, wholly made up of one or other of these elements, as we pass over them from south to north, they are everywhere precisely similar, barren, monotonous, and uninviting.

Lying at intervals among these unfossiliferous greywackes occur thick bands of black carbonaceous shale, loaded with Graptolites, and associated with beds of barren mudstone, grey, green, purple, and occasionally pure white. These very distinctive strata run longitudinally through the district in the direction of the strike, or are exposed in long lenticular areas of small diameter. Being much softer than the greywackes amid which they repose, they are more easily destroyed by the action of the elements, and are usually eroded into narrow valleys or form the beds occupied by the smaller mountain-streams. The line of demarcation between them and the greywackes everywhere gives rise to a prominent physical feature, apparent even upon the turf-covered slopes. In the streams the divisional line is in general strikingly marked by a picturesque cascade, the water plunging over a precipice of grit into a deep black hollow, worn out of the soft mudstones below. The strata proper to the shale-bands are at once distinguished, by their colour, composition, and texture, from the rocks among which they lie; and where they cross the steeper ridges their place is marked by a deep red gash or score in the mountain-side, strongly relieved against the dark heather-clad slope, and visible at a great distance.

The black carbonaceous shales are highly pyritous, and the waters that flow through them are all more or less impregnated with sulphate of iron. The mudstones themselves and the banks of the streams for some distance below each exposure are normally stained of a deep red or bright orange-colour by the mineral deposit from the waters. The springs that rise among the shales, or are immediately derived from them, afford the chalybeate waters for which the district has long been celebrated. To the presence and efficacy of these springs is owing the material prosperity of the flourishing town of Moffat, the only place of importance in the district, and, at present, the most fashionable watering-place in the south of Scotland.

The title of Moffat Series, or Moffat Shales, by which these remarkable deposits have long been known to geologists, is thus singularly appropriate; and as these rocks attain here their fullest development, and at the same time are most satisfactorily exhibited, this title is certain eventually to supersede all others as the general name for all the Scottish graptolitiferous deposits of corresponding age.

At least four distinct bands of the dark shales are traceable to the south of the Moffat-Yarrow valley, and one of them is prolonged in a broken line far beyond the south-western limits of the district. A larger number are apparent to the north of the central valley; but in none of these are the exposures so continuous or satisfactory.

Exception being made of a narrow strip of country in the neighbourhood of St. Mary's Loch, where the strata have a southward inclination, all the rocks of the district, greywackes and mudstones

alike, dip uniformly to the N.N.W. at high angles. Faults, folds, and inversions are occasionally visible among the greywackes; but in the dark shales they are astonishingly abundant. In every known locality where the Graptolitic beds are exposed, the majority are in this contorted and dislocated condition, and the attempt to ascertain their interrelationship by lithological and stratigraphical evidence has soon to be abandoned as hopeless. Their separation by zoological characters appears quite as desperate; for in many localities every trace of their former prolific fauna has been obliterated; in others only one or two fragmentary forms are obtainable, and these are limited to a few inches of thickness of the less altered zones. Even in those bands where the fossils are numerous and well preserved, the neighbouring exposures have frequently not a single fossil in common.

It is to the consideration of the numerous facts recently made out regarding the black Graptolitic shales that the present paper will be devoted. These peculiar rocks are quite as abundant in other districts, but it is here that they attain their maximum thickness and yield their most varied fauna. At the same time they are here less metamorphosed than elsewhere; and consequently here, if anywhere, will the problems they suggest admit of a satisfactory solution.

In the following pages I shall endeavour to prove that, in spite of the uninviting and, indeed, highly perplexing features of these deposits as here exhibited, we have actually within the limits of the present district more than sufficient stratigraphical and palæontological evidence to enable us to piece together the shattered fragments of this important rock-group, and in this way to fix the original sequence of its component beds, to mark out the distinguishing fossils of its various zones, to determine with certainty their geological age, and to point out their representatives in foreign countries.

§ III. *History of previous Opinion.*

It is to Prof. Sedgwick that we owe the earliest detailed notice of the rocks of the Moffat district. In his memoir "On the Geological Structure and Relations of the Frontier Chain of South Scotland" *, read at the meeting of the British Association at Glasgow in 1850, he arranged the rocks of the Southern Uplands into five successive formations. The lowest and most ancient of these formations, which he denominated the Moffat Group, embraced the majority of the strata of the present district. It was defined as "a great thickness of arenaceous rocks, in which pyritous and Graptolitiferous schist abounds to such an extent that the arenaceous beds become sometimes subordinate to it." His second group, for which he proposed no distinctive title, included the much broader mass of greywackes to the northward, apparently destitute of the aluminiferous schists.

But the most valuable and important paper hitherto published upon the rocks of the Moffat neighbourhood is the memoir by Prof.

* Rep. Brit. Assoc. 1850, pp. 103–4.

Harkness, "On the Silurians of Dumfries," presented to the Geological Society of London in 1850 *.

The author clearly recognized the fact that the pyritous shales are arranged in long lines among the barren greywackes, and gave a brief description of several localities along the three parallel bands of Hartfell, Frenchland, and Craigmichan, tracing these bands for many miles through the district, and hinting their probable extension from sea to sea. Giving a general account of their peculiar strata, their mineral character and fossils, he called especial attention to the remarkable similarity of the rocks of the three bands, pointing out at the same time their excessive convolution, fracture, and local metamorphism. From these facts he drew the most important inference that they were originally portions of one and the same deposit. Their present position he attributed to three gigantic faults running through the district parallel with the general strike of the beds. The arenaceous strata among which they are imbedded, he believed to be of the age of the Caradoc Sandstone of Siluria.

The same year Sir Roderick Murchison, in his memoir "On the Silurian Rocks of the south of Scotland" †, made several important allusions to the strata of the district, some sections of which he had himself hastily examined under the guidance of Prof. Harkness. He expressed his willingness to accept Harkness's theory of the identity of the strata forming the anthracitic bands; but preferred to interpret their geographical position on the hypothesis of great folds, the upper arches of which had been denuded. At the same time he emphatically assigned to the whole of the rocks of the district a geological position inferior to that of the Bala Limestone of North Wales. He seems to have been especially struck with their shattered and convoluted aspect, acknowledging that "all inferences drawn from physical appearances must indeed be deceptive in so tortuous and convulsed a region."

The fossils of the black bands have been subsequently figured and described by Messrs. Carruthers and Hopkinson, Prof. Nicholson, and others; and many references to the relationships and geological position of the dark shales have been published by various geologists, but no physical facts obtained within the district itself have hitherto been brought forward in support of their conclusions.

The task of determining the interrelationships of these enigmatical deposits, though in truth a very simple one, has been but slowly accomplished. The scale even of the 6-inch maps was soon ascertained to be insufficient to allow of the insertion of all the natural subdivisions of the dark shales; and they had to be supplemented by enlarged sketch plans of all the more important exposures. The caution requisite in proving and reproving every important point, stratigraphical and palæontological, in a region so excessively disturbed has necessitated the accumulation of a mass of confirmatory and supplementary evidence, sufficient to place wholly beyond cavil all the data upon which our conclusions are founded.

The determination of the geological age of the Moffat strata, and

* Quart. Journ. Geol. Soc. vol. vii. p. 46 *et seq.* † *Ibid.* vii. p. 139.

the correlation of their subdivisions with their foreign equivalents, would till recently have been practically impossible. In this connexion I have been presented with many facilities denied to former investigators. The valuable papers by Mr. Hicks on the sequence and fossils of the various subformations of the Cambro-Silurian of South Wales have been of especial service to me. From several other eminent observers I have also to acknowledge most important aid. To Mr. J. Hopkinson I am indebted for much of my knowledge of the Graptolithina of Wales. Professor H. A. Nicholson placed at my disposal the results of his researches in the Lake district. Dr. G. Linnarsson, of Stockholm, furnished me with a complete summary of the facts hitherto collected by the Swedish Survey with respect to the range of the Graptolithina in the Scandinavian Silurians. Through the kindness of the three last-named gentlemen I have been enabled to compare the organic remains of the Moffat rocks species for species with those of their extra-Scottish representatives.

Much of the district under description was worked over in company with my friend Mr. James Wilson; and my study of the fossils of the dark shales was greatly facilitated by the aid afforded me by several observers who had already made collections from these strata outside the limits of the Moffat district. Among others I have especially to thank Mr. W. Swanston, of Belfast, and Messrs. D. J. Brown and W. Dairon, of Glasgow.

A. Physical Relations of the Moffat Series.

§ I. (a) *Description of the typical Section of Dobb's Linn.* (Plate XII. Sections I., II., III.)

The only section of the Moffat Series which allows us to determine with certainty the sequence and palæontological characteristics of its component beds, and at the time clearly exhibits the relationship of the group as a whole to the surrounding greywackes, occurs in the centre of the Moffat district, about midway along the longitudinal depression already referred to. The highway from Selkirk to Dumfries, which runs upon the floor of this depression, crosses the main watershed at the spot marked by the little cottage of Birkhill, and begins to descend the long straight valley of Moffatdale to the south-west. About half a mile below the cottage three small streams of nearly equal volume meet at the same point to form the infant Moffat. Two of these streams dash down the steep slopes bounding the valley to the south-west; but as they flow over thick beds of hard grit, their courses are comparatively shallow and insignificant. The third stream, however, which descends from the north-west, emerges from a gloomy hollow dug deep in the flank of the rugged ridge that shuts in the main valley to the north.

Entering this hollow at its foot, it is seen to be a narrow rugged gorge, deriving its forbidding appearance from the black shales that close it in, and mount up on both sides in naked cliffs of great

height. Near its centre it is joined by a second gorge, narrower and deeper, and terminated abruptly by a precipice of grit. Above the precipice two small streams draining the moory mountain-tops to the west unite, and hurl their waters down the cliff in two successive leaps to the bottom of the chasm, which, like the longitudinal hollow itself, has been excavated wholly in the black and grey shales of the Moffat Series.

This picturesque cascade, which is known as Dobb's Linn, gives its name to the whole glen. Like many of the deep rugged gorges that relieve the smooth undulating monotony of the Uplands, the place has its legends of the Covenanters, bloody and quaint, so that, apart altogether from its weird scenery, the spot has long enjoyed a local reputation.

To the geologist visiting the glen for the first time the section of the shales and mudstones afforded by the northern cliff of the lateral gorge is that which, above all others, commends itself to his notice, as it is visible from end to end, and, exception being made of a few local contortions, the strata exhibited appear to follow each other in natural and unbroken sequence. The coarse grits and flagstones of the falls dip at 70° or 80° to the east, and plunge visibly beneath a thick series of grey shales with black bands. This group is followed first by a group of black shales, and next by a similar thickness of greenish-grey mudstone. Upon the latter reposes a second series of black shales, much thicker, and quite distinct in its general features from that already noticed, forming clearly the final member of the Moffat Series as here exhibited, and passing beneath the greywackes of the eastern cliffs at a low angle. So clear are these facts, and so obvious the conclusions to which they point, that no one would hesitate to infer that the Moffat beds of this locality constitute a single band of fossiliferous shales and mudstones, composed of three members, and actually interbedded in the great barren greywacke series. (Plate XII. Section I.)

If, however, we select any one of the well-marked zones of black, white, or green mudstone so conspicuously exhibited at this spot, and follow it carefully in its outcrop, first up the south cliff, and thence across the face of the steep slope on the right-hand side of the longitudinal gorge, it will be ascertained that it gradually undergoes a complete reversal of its original inclination, until, finally, in a magnificent cliff-section about 100 yards from our starting-place, all the zones we have recognized in the lateral gorge, together with others not there apparent, and inclusive also of the coarse grits and flagstones of the waterfall itself, are now arranged in the opposite order, and dip steadily at a gentle angle to the W.N.W.

Thus, in the two chief sections of the glen, the order of succession deduced from the evidence afforded by the one is completely contradicted by that of the other. It is clear that in one of these sections the strata must be inverted; and we are thus taught at the very outset of our inquiry how utterly futile is the endeavour to determine the original sequence of these deposits merely by attention to

their *apparent* order of superposition in any single section, however perfect.

(a) *Subdivisions, Characteristics, and Inter-relationships of the Strata exhibited in the typical section of the Main Cliff.*

The only locality in the glen where the junction of the greywackes with the dark shales and mudstones is distinctly visible for some distance is in the floor and sides of the lateral gorge immediately below the falls (Plate XII. Sect. I.). Here the sequence from the greywackes for at least 100 feet into the very heart of the Moffat beds is seen to be unbroken; and the evidences afforded by the bed of the stream can be easily checked and supplemented at every stage of our inquiry by a comparison with the frequent exposures of the same strata in the South Cliff, in the floor and walls of the steep "corrie" to the north-west, or along the bottom of the little rill that trickles down its centre.

Commencing with the greywackes of the falls, which, dipping to the south-east at a very high angle, visibly pass below all the mudstones and shales of the glen, and reading off the characters of the consecutive beds in what thus appears to be the ascending order, we note the following succession (Vertical Sect. fig. 1, p. 250) :—

(I.) *First or Birkhill Division.*

(i.) *First Grey-Shale Group.*

	ft.
1. Grey and greenish shales and flaggy beds	15
2. Grey shales containing four black bands, from 2 to 4 inches in thickness, and occasional laminæ of soft shaly clay of a pure white or cream-colour. Graptolites are numerous in the black seams. The most characteristic forms are *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.)	10
3. Grey shales with white-clay bands, barren of fossils	15
4. A peculiar assemblage of black, white, and greyish-brown shales and mudstones. Some of the dark mudstones are soft and highly pyritous. A few thin seams are sandy and harsh to the touch. The latter are sometimes cut up superficially into lozenge-shaped reticulations by a series of shallow grooves, somewhat resembling sun-cracks, but always perfectly straight throughout. Fossils are abundant in the darker beds. The most prevalent forms are *Monograptus Sedgwicki* (Portlock)=*M. spinigerus* (Nich.) and *Monograptus Hisingeri* (Carruthers).	10
5. Grey mudstones, with seams of white clay	15
Near the middle of this band occurs a thin seam of black shale, which is well shown at the head of the Corrie. It is about 6 inches in thickness, and is charged with *Monograptus Clingani* (Carr.) and *Rastrites hybridus* (L.). Immediately below the fossil-bed in this section is a curious seam of dark grey mudstone, covered with the trains of Annelides, and full of small nodular concretions.	
6. Zone of highly pyritous black shale, disintegrating into small flaky fragments, which are coated with a rusty film of iron oxide, or flowers of alum. It is crowded with poorly preserved specimens of *Monograptus lobiferus* (M'Coy), *Diplograptus cometa* (Gein.)	8
This is covered by 4 feet of barren grey shale, above which follow the first beds of the succeeding black-shale group.	

Fig. 1.—*Vertical Section, showing the Subdivisions of the Moffat Series of Dobb's Linn and Craigmichan Scaurs.*

	Gala or Queensberry flagstones and Greywackes.	
Birkhill Shale. — Upper Birkhill.	*Cb*³. Zone of *Rastrites maximus* (Carr.). Grey flaggy shales, sometimes purple, containing four seams of dark carbonaceous shale with fossils.	No fossils. *Rastrites maximus, Monograptus turriculatus, M. proteus, M. involutus, M. intermedius, M. runcinatus, M. Becki, Peltocaris aptychoides.*
		No fossils.
	*Cb*². Zone of *Monograptus spinigerus* (Nich.). Black and grey shales, with seams of white clay.	*Monograptus spinigerus* (=*Sedgwicki*), *M. Hisingeri, M. tenuis, M. attenuatus, Diplograptus Hughesi, Retiolites perlatus, Rastrites hybridus, R. capillaris.*
		Horizon of *Monograptus Clingani.*
	*Cb*¹. Zone (sub-)of *Diplograptus cometa* (Geinitz). Black and grey shivery mudstones.	*Diplograptus cometa, D. sinuatus.*
Lower Birkhill.	*Ca*³. Zone of *Monograptus gregarius* (Lapw.). Black flaggy shales, with lines of coloured clays and seams and nodules of iron-pyrites.	*Monograptus leptotheca, M. lobiferus, Rastrites peregrinus, Diplograptus tamariscus, Discinocaris Browniana, Eurypterus*, &c., *Monograptus fimbriatus, M. argutus, M. triangulatus, M. Sanderson, M. communis, M. concinnus, M. cyphus, Diplograptus palmeus, D. physophora.*
	*Ca*². Zone of *Diplograptus vesiculosus* (Nich.). Hard black carbonaceous flags.	*Diplograptus vesiculosus, Climacograptus innotatus, Monograptus tenuis, M. attenuatus.*
	*Ca*¹. Zone of *Diplograptus acuminatus*. Shivery shales—black, brown, and yellow.	*Diplograptus acuminatus, Dimorphograptus elongatus.* *Climacograptus scalaris.*
Hartfell Shale. — Upper Hartfell.	*Bb*². Zone of *Dicellograptus anceps* (Nich.). Soft green shales, with seams of black and white mudstones.	*Dicellograptus anceps, Diplograptus truncatus.* *Climacograptus bicornis.*
	*Bb*¹. "Barren Mudstone." Light green flaggy mudstones.	No fossils.
Lower Hartfell.	*Ba*³. Zone of *Pleurograptus linearis* (Carr.). Hard black slaty shales, with seams of white mudstone.	*Dicellograptus, Diplograptus.* *Pleurograptus linearis, Amphigraptus divergens, Leptograptus flaccidus, Diplograptus quadrimucronatus, Dicellograptus elegans.*
	*Ba*². Zone of *Dicranograptus Clingani* (Carr.). Hard black flags and slaty shales.	*Eurypterus*?, *Siphonotreta micula, Acrotreta Nicholsoni, Dicellograptus Forchhammeri, D. Morrisi, D. moffatensis, D. caduceus, Dicranograptus Clingani, D. ramosus, D. Nicholsoni, Retiolites fibratus, Climacograptus caudatus, Dictyonema moffatensis.*
	*Ba*¹. Zone of *Climacograptus Wilsoni* (Lapw.). Flaky shales and mudstones—black, brown, and spotted.	*Climacograptus Wilsoni, C. Scharenbergi, C. bicornis, Diplograptus tricornis, D. foliaceus, Glossograptus Hincksi, Lasiograptus Harknessi.*
Glenkiln Shale. — Upper Glenkiln.	*Ab.* "*Didymograptus*-beds." Highly pyritous slaty black shales and flags, with beds of pale shivery mudstones.	*Cœnograptus gracilis, C. surcularis, C. pertenuis.* *Didymograptus superstes.* *Dicellograptus divaricatus, D. sextans.* *Dicranograptus formosus, D. ziczac, D. Nicholsoni.* *Diplograptus dentatus, D. Whitfieldi.*
		Thamnograptus typus. *Clathrograptus cuneiformis.*
Lower Glenkiln.	*Aa.* "Ribbed Mudstones." Thick beds of pale non-fossiliferous mudstone, with seams and ribs of hard grey flags.	No fossils.

In this section consequently the first grey-shale group attains a collective thickness of about 77 feet. If we connect each of its non-fossiliferous bands with the special Graptolitiferous seams immediately above, the whole group may be regarded as falling into three distinct zones. The first of these zones is marked by the exclusive presence of *Rastrites maximus*, the second by that of *Monograptus spinigerus* and the third by the preponderance of *Diplograptus cometa*.

Next in importance to the very distinctive aspect given to the group as a whole by the alternation of broad bands of grey and black shale, the most striking mineralogical feature is formed by its intercalated seams of white clay or mudstone. These characteristic beds vary in thickness from an inch to a foot, and, when weathered, break up into small flakes about the size and thickness of a finger-nail. These clay bands abound in the South Cliff and in the walls of the corrie; their thin chaff-like fragments are scattered over the whole section of the grey-shale group, giving it a most peculiar appearance, and effectually distinguishing it from all the remaining beds exposed in the lateral gorge.

(ii.) *First Black-Shale Group.*

Continuing our catalogue of the rocks of the glen, we notice that the grey-shale group is followed by a thick series of black shales, crowded with fossils, and arranged in the following order :—

(*a*) A mass of black flaggy shales and mudstones 30 feet in thickness. In the first half of this zone the beds are thin, soft, and highly pyritous; the remainder are hard and flag-like. Throughout the whole mass there occur at intervals seams of blue, yellow, or orange-coloured mudstone or clay, varying from a few inches to nearly a foot in thickness. Many of these brightly coloured beds contain lines of calcareous concretions and balls of nodular iron-stone. One very large band of nodules occurs in the very centre of the zone, dividing it into two portions, lithologically and palæontologically distinct.

The characteristic fossil of the whole zone is *Monograptus gregarius* (Lapw.). Its first division is marked by the exclusive presence of *Rastrites peregrinus*, and the second by that of *M. Sandersoni*.

These beds, after a slight contortion in the walls of the corrie, are cut off abruptly from the strata which naturally follow them by a north and south fault, crossing the line of strike of the rocks at a small angle, and bringing them against a great thickness of pale unfossiliferous mudstones to be described in the sequel.

Leaving the lateral gorge at this point, and examining next the beautiful section in the Main Cliff (Sect. II. Plate XII.), we notice that the grey-shale group of the corrie crosses the cliff immediately below its highest point. It is in such a position that it cannot be reached with safety, but the grey, black, and white bands are easily identified from below. Instead of lying upon the coarse grits of the falls, as in the lateral gorge, it here visibly passes underneath them at an angle of about 45°.

Immediately below the grey shales lies the thick series of black shales already described, forming the first division of our first black-shale group. Its coloured and nodular bands can be seen crossing the cliff below the grey shales, and all its characteristic fossils can, by the exercise of ordinary caution, be collected along the edge of the cliff.

These beds are here underlain by the strata missing from the lateral gorge, viz.:—

(*b*) A zone of black flags, in beds of about 1 foot in thickness. These rocks are remarkably resistant of atmospheric influences, and form a jutting ledge running across the face of the cliff, overhanging and protecting from degradation the more tractable beds immediately below.

Fossils are abundant, but of few species. The commonest form is the strange *Diplograptus vesiculosus* (Nich.), which, usually associated with *Climacograptus scalaris* (His.), swarms in extraordinary profusion in some of the beds.

(*c*) The hard *D.-vesiculosus* beds repose upon a similar thickness of finely laminated black shales, weathering down into thin flakes of a pale yellow colour. They contain a smaller proportion of carbonaceous matter than the overlying beds, and are softer and less fossiliferous.

They are characterized by the exclusive presence of *Diplograptus acuminatus* (Nich.).

The lowest band of this zone is very peculiar. It consists of about a foot of tough slightly calcareous shale, weathering of a dark brownish drab, or gingerbread-colour, and affording numerous examples of *Climacograptus scalaris* in a state of high relief.

At this point a sudden and most extraordinary change takes place in the genera and species of the fossils of the Moffat Series. Scarcely a single form of those collected by us in the strata already described is met with in any of the beds below this line, which are, however, like those above it, linked together by a large community of organic forms. Here, therefore, is the chief palæontological break in the succession, and here, consequently, are we compelled to draw our main line of demarcation in any natural classification of the Moffat Series of this locality.

The palæontologist who makes a detailed study of the fossils of that portion of the Moffat Series already passed under review will soon assure himself of the fact that each species and variety of Graptolite &c. has a definite range in the vertical succession of strata. None pass from the lowest to the highest zone; a few run up through the majority of the beds; several are common to two or three subdivisions; and the remainder are restricted to even narrower limits. Some (and these are the most valuable for our present purpose) are strictly confined to one or other of the mineralogical zones we have indicated above.

Further, it will be ascertained that the most prevalent forms in these beds belong to the unilateral genera *Monograptus* (Geinitz) and *Rastrites* (Barr.) of the family of the Monograptidæ. Below

our great divisional line their place is taken by the bilateral genera *Dicranograptus* (Hall) and *Dicellograptus* (Hopk.) of the very distinct family of the Dicranograptidæ.

The beds above this separating line, which thus compose the first natural division of the Moffat Series as here displayed, I distinguish by the title of the Birkhill Shales, after the name of the watershed in the immediate neighbourhood.

(II.) *Second or Hartfell Division.*

A single glance at the strata that underlie the Birkhill Shales of the Main Cliff, and thus constitute the second provisional division of the Moffat Series, is sufficient to assure the geologist of the fact that, like the beds of our first division, they fall naturally into two very distinct lithological groups. The higher of these groups is made up of 50 feet of green, grey, and brown shales and mudstones, with a few intercalated lines of black shale, and the lower of 45 feet of hard black slaty shales and flagstone.

The upper group of pale mudstones is, again, clearly formed of two distinct subdivisions, viz. :—

(*a*) A superior zone of soft green, yellow, white, and black mudstones. The black lines in the mudstones swarm with badly preserved examples of *Dicellograptus anceps* (Nicholson).

(*b*) An inferior zone of pale greenish-grey flaggy mudstones, about 30 feet in thickness, totally devoid of fossils except in a small line about 2 inches in depth near its base.

The inferior, or black-shale group may most conveniently be regarded as composed of three zones :—

(*a*) The highest zone is formed of hard black slaty shales, varied by thin cream-coloured seams of white mudstone. Fossils are abundant, the most characteristic being the peculiar *Pleurograptus linearis* (Carr.).

(*b*) The middle zone is formed of similar hard black shales, but it includes several bands of tough siliceous black flags, about 2 inches in thickness, while the white seams of the zone last described are absent throughout.

The characteristic fossil is *Dicranograptus Clingani* (Carr.).

(*c*) The lowest zone is composed of dark greyish-black flagstones and shales totally destitute of fossils except in three or four thin seams, where they occur in a state of exquisite preservation.

The most abundant species is *Climacograptus Wilsoni* (Lapw.).

This second division of the Moffat Series is denominated the Hartfell Shales, after the locality where its beds are most perfectly exhibited, which will be described in detail in the next portion of this paper.

(III.) *Third or Glenkiln Division.*

The Birkhill and Hartfell Shales include the whole of the beds exposed in the Main Cliff, with the exception of a narrow wedge of dark flagstones, 15 feet in thickness, visible at its south-west corner.

The strata referred to are, many of them, highly siliceous, and weather down into small cuboidal fragments. Fossils are not uncommon in the partings of soft black mudstones. The most distinctive are *Thamnograptus typus* (Hall) and *Didymograptus superstes* (Lapw.).

It will be shown in the sequel that these beds appertain to a third division of the Moffat Series. To this division I have given the title of the Glenkiln Shales, from the spot where it yields its characteristic fossils in the greatest abundance.

Summary.

Disregarding for the present the small patch of Glenkiln Shales last described, it is evident that the strata of the Moffat series exhibited in the Main Cliff of Dobb's Linn are naturally arranged in two main divisions palæontologically distinct. Each of these divisions, again, falls naturally into two well-defined mineralogical subdivisions, each of which is, in turn, composed of several subordinate bands or zones, individually distinguishable by peculiar lithological and palæontological features. Arranging the strata in the order in which they are here displayed, and distinguishing each band by its predominant or peculiar fossil, we have the succession given in the following Table :—

III. Birkhill Shales.	*Upper Birkhill* or Grey-Shale Group.	Zone of *Rastrites maximus*, Carr.	
		Zone of *Monograptus spinigerus*, Nich.	
		Subzone of *Diplograptus cometa*, Gein.	
	Lower Birkhill or Black-Shale Group.	Zone of *Monograptus gregarius*, Lapw.	
		Zone of *Diplograptus vesiculosus*, Nich.	
		Zone of *Diplograptus acuminatus*, Nich.	
II. Hartfell Shales.	*Upper Hartfell* or Barren-Mudstone Group.	Zone of *Dicellograptus anceps*, Nich.	
		Zone of "Barren Mudstone."	
	Lower Hartfell or Black-Slate Group.	Zone of *Pleurograptus linearis*, Carr.	
		Zone of *Dicranograptus Clingani*, Carr.	
		Zone of *Climacograptus Wilsoni*, Lapw.	

I. Glenkiln Shales.

(b) *Section along line* A–B. (Plate XII. Sect. I.)

With this provisional key to aid us, we proceed next to test its accuracy by endeavouring to work out therewith the physical arrangement of the Moffat Series of the main body of the glen.

Returning to the lateral gorge beneath the falls, the section of the North Cliff is resumed at the point where we left it, *i. e.* at the north and south fault, by which the *M.-gregarius* zone of the Birkhill Shales is brought into contact with the great band of barren mudstone. The North Cliff itself is divided into four distinct ridges by three deep bays or "scores." The fault referred to runs up the centre of the western score. Following its direction carefully up the face of the cliff, it is seen to cut the line of strike of the beds at

a very acute angle; and the lower zones of the Birkhill Shales, wanting in the floor of the lateral gorge, come in visibly one by one on the western side of the fault.

The *M.-gregarius* zone seen in the burn is followed in the cliffs immediately by the zone of hard thick-bedded black flags with *Diplograptus vesiculosus*. Here, exactly as in our type section of the Main Cliff, these flags form the most prominent portion of the slope, overhanging and protecting the subjacent and softer beds. The *D. vesiculosus* band is followed in turn by the zone of *D. acuminatus*, with its shivery shales of greyish black, and the peculiar calcareous brownish gingerbread-coloured band at its base, swarming with the same exquisitely preserved fossils.

Upon the drab line reposes the green-shale band, of about 6 feet in thickness, that constitutes the upper portion of the *D.-anceps* zone of the highest Hartfell Shales of the Main Cliff; and next follows the fossiliferous portion of the *D.-anceps* zone itself. The latter forms the north-west wall of the upper part of the West Score, and is crushed up in a sharp fold against the fault, which probably dies out a few feet beyond. Not many of the fossils of the *D.-anceps* zone are procurable from the smashed beds, but quite sufficient to show that they are identical with those of its prototype in the Main Cliff.

Crossing the line of fault, an apparent thickness of 60 or 70 feet of barren green mudstone is passed over in the North Cliff and the bed of the stream, a thickness it is very difficult to reconcile at first sight with the 30 feet of the same rock as exposed in our typical section. A careful attention to the lithological characters of the beds, however, soon reveals the fact that this excessive thickness is due to folding. Near its southern termination we recognize the thin black fossiliferous line of the band, here repeated two or three times.

Next in order comes the thin-bedded slaty-shale zone (*Pleurograptus linearis*), forming the highest subdivision of our *Lower Hartfell* Shales, the line of junction between it and the very differently coloured mudstones of the preceding zone forming a long straight line up the face of the North Cliff. The beds of this zone form a prominent portion of the summit, and yield all its fossils in abundance.

These beds are succeeded in the cliff by the *D.-Clingani* zone of hard black slaty shales. At the top of the cliff they are beautifully exhibited (but in a highly-contorted condition) near the head of the East Score, and are prolonged in some rugged bosses of black rock that protrude through the turf much further to the north. The distribution of their included fossils, *Dicellograptus Forchhammeri*, *D. caduceus*, *Dicranograptus ramosus*, *D. Clingani*, &c., makes it certain that these convoluted beds are portions of one and the same thin zone.

Up to this point, then, it is perfectly clear that the succession among the beds in the North Cliff, from the greywackes of the falls to the Lower Hartfell Shales, is identical in every respect with that in our typical section of the Main Cliff. Here, however, the strata

are reversed in position, and their relations are complicated locally by visible faults and convolutions.

Continuing our section beyond the zone last described, we come immediately upon beds of a totally distinct character from any of the Hartfell Shales. These strata constitute a band of hard thick-bedded black flags, forming the highest ledge of the Long Cliff, and standing up almost on end like a broad wall. Their appearance and behaviour instantaneously call to mind the conspicuous *D.-vesiculosus* bands of the Birkhill Shales; and their identity with them is soon placed beyond question by the detection of numerous examples of *Diplograptus vesiculosus*, and its constant associates *Climacograptus innotatus* and *Monograptus tenuis*.

Between this band and the thin-bedded *D.-Clingani* zone of the summit of the cliff must necessarily occur a fault of some magnitude, as almost all the Hartfell shales, and several of the Birkhill zones, are missing from between them. This, as we shall presently ascertain, is a portion of the most important fault in the rocks of the glen.

At the eastern foot of the wall formed by the *D.-vesiculosus* band lies the shivery *D.-acuminatus* band, dipping below the former in the same attitude as in the Main Cliff. It swarms with its characteristic fossils, and affords several excellent exposures of the peculiar gingerbread-coloured bed at its base.

This zone reposes immediately upon the six-foot mudstone of the *D.-anceps* zone, which forms a pale band running obliquely up the Long Cliff for some distance, very conspicuous among the dark shales by which it is surrounded. It is underlain in its turn by the fossiliferous and variegated portion of the *D.-anceps* band, admirably exposed, and swarming with *Dicellograptus anceps*, *Climacograptus tuberculatus*, &c.

Between this point and the great fault at the summit of the cliff these three zones of *D. vesiculosus*, *D. acuminatus*, and *Dicellograptus anceps* are arranged in the same order as in the Main Cliff, and have a corresponding dip to the west. But passing upwards beyond the *D.-anceps* zone the sequence becomes greatly confused; the rocks are so convoluted and shattered that any attempt to unravel them along this line appears a well-nigh hopeless task. These contorted beds are clearly crushed against a line very slightly transgressive upon the *D.-anceps* zone, which itself everywhere retains the steady strike and dip of the pale mudstone band immediately above it. It is therefore highly probable that we have here a third line of fault, running generally along the base of the *D.-anceps* zone.

That this is actually the case is proved at once upon an examination of the succeeding contorted beds. Everywhere to the north and south of our line of section they show the characteristics of the *M. gregarius* zone of the Birkhill Shales—the red, blue, and yellow seams of clay, the peculiar lines of nodular concretions, together with swarms of the distinctive fossils, *M. gregarius*, *Rastrites peregrinus*, *Diplograpsus tamariscus*, &c.

This fault can be traced from a point near the centre of the upper

edge of the Long Cliff, down the base of the *D.-anceps* zone into the Long Burn, at a point near its lower termination. The contorted *M.-gregarius* beds which bound it on the east form the whole of the Long Cliff, below the fault, from end to end, for a distance of about 300 yards. Towards the north the contortion gradually decreases in intensity till near the upper extremity of the gorge, where we have a complete confirmation of our reading of the cliff-structure. Here the *M.-gregarius* zone we have traced upwards shows all its component strata dipping in regular (but inverted) order, and yielding its peculiar fossils in a finer state of preservation than anywhere else within the limits of the glen. It passes down gradually, bed upon bed, into the conspicuous *D.-vesiculosus* zone, the thick flaggy strata of which form the steep walls of the head of the gorge, and expose beyond them traces of the shivery *D.-acuminatus* zone, and of some pale-green strata that may belong to the Barren Mudstone.

To complete our section we have finally to ascertain what are the beds that lie between the contorted *M.-gregarius* zone of the Long Cliff and the grits and flagstones that are visible occasionally along the upper edges of the East Cliff, forming the boundary of the Moffat Series in that direction. Unfortunately immediately in our line of section the required beds are almost wholly obscured by turf and talus. At one spot, however, near the centre of the Long Burn, where it commences its north-westerly curve, several of the beds of which we are in quest are shown in a fine cliff-section. They are seen to consist of thin bands of grey shales and mudstones, with here and there a thin black line. Among them occur several seams of pure white clay, weathering into small flaky fragments, which are scattered over the whole section, and give it a most peculiar appearance when viewed at a little distance. It is impossible to doubt for a moment that we have before us the first Grey-shale group, or Upper Birkhill Shales of the waterfall, which, however, instead of reposing upon the greywackes, actually pass beneath them at a low angle. The few fossils procurable, which include *Monograptus spinigerus* (Nich.), *M. Hisingeri*, and *Diplograptus Hughesi*, distinctly confirm this conclusion, as also does the fact of the presence of the hard grey band forming the base of the group, which is seen running from side to side of the bed of the little stream immediately below. A little further to the north, and in the contorted beds above, several additional Upper Birkhill Graptolites are obtainable.

Beds belonging to the same set of grey and black shales crop out at intervals along the whole remaining length of the East Cliff below the greywackes, between the latter and the contorted zone of *M. gregarius*; and their precise identity with those of the grey group of the corrie is placed wholly beyond doubt when the several exposures are examined in detail, the sequence of the various bands agreeing with those of the latter in every respect.

The study of this section of the North Cliff has taught us that in the upper portion of the glen there are no black shales present that do not belong to the Moffat Series, as exposed and tabulated in our typical section of the Main Cliff; and, further, that as the zones in

contact with the greywackes at both ends of the section are identical, although they dip in the same direction, it is clear that we have here a faulted anticline or syncline, the axis of which is inverted.

(c) *Description of the Section along line* C–D.
(Plate XII. Sect. II.)

This section crosses the Main Cliff near its southern extremity, at right angles to its general direction. Its western half is made up of the strata enumerated in our typical section, and the total exposure of the Moffat Shales along its course is reduced to a little more than half the diameter of that on our former traverse.

Commencing at the summit of the Main Cliff, the coarse greywackes of the falls are seen dipping at a gentle angle to the west, off the Grey-shale group; and, descending the line of section, the various strata of the Birkhill, Hartfell, and Glenkiln divisions, as tabulated, are passed over in orderly succession. Thrust abruptly against the patch of Glenkiln Shales in the southern angle of the cliff, and dipping generally in the same direction, are some contorted grey and black bands yielding a few fragments of Birkhill forms. These become more numerous in some bosses of hard, flaggy, and contorted black shale, through which the stream cuts its passage, and include *D. vesiculosus*, *D. tamariscus*, and *M. gregarius*. The presence of some nodular and coloured clay bands at this spot are an additional evidence that these beds belong mainly to the *M.-gregarius* zone. This is at once proved to be the case if we follow them in their course along the east bank of the stream to the northward, where in a naked portion of the East Cliff, a short distance below the foot of the Long Burn, they are exhibited in a magnificent exposure. Every characteristic of the *M.-gregarius* zone is here apparent, the large central nodule-band being especially conspicuous among the contorted strata, and the special fossils obtainable in great profusion.

Between this contorted zone (which is visibly the southerly continuation of the contorted *M.-gregarius* zone of our former section) and the wedge of Glenkiln Shales at the foot of the East Cliff must therefore be a fault cutting out the whole of the Hartfell Shales. A glance at the map (Pl. XI.) will show that this is the southerly continuation of the main fault of the North Cliff detected in our former section.

Reposing upon this contorted *M.-gregarius* zone, and passing below the greywackes that form the higher portion of the East Cliff, are the grey and black bands of the *Upper Birkhill Series*. They are exposed only in fragmentary patches in some of the numerous scores that furrow the talus-covered slope; but, as already mentioned, the zones of *M. Sedgwicki* and *M. cometa* are plainly discernible, and the characteristic white-clay bands may be detected everywhere among them on clearing away the overlying *débris*.

Thus on both sides of this section the thick barren greywackes and flagstones of the surrounding country are the highest beds, and they are in both cases immediately underlain by the Grey-shale group of the Birkhill Shales, which in its turn is supported by the nodular or *M.-gregarius* zone.

We are furnished in this way with a complete and convincing reply to the question left unanswered by the evidence of our previous sections. We have now no choice but to regard the Moffat Series in the glen as being arranged in an anticlinal form; and at the same time the sequence of its component beds, as displayed in our typical section of the Main Cliff, is thus demonstrated to be the natural order of succession.

(d) *Physical Structure of the Glen.*

We are now able to comprehend fully the physical arrangement of the strata exposed within the Glen. The Moffat Series of this locality, is disposed in the form of a rude arch, which is broken by three longitudinal faults. In the centre of the Glen the plane of the main axis of the anticlinal is approximately perpendicular, and the beds are shown in their natural position. To the northward the axis dips to the eastward, and the strata upon its western side are all inverted. In the southern portion of the Glen, on the other hand, the axis dips to the westward, and it is the eastern beds which are overturned.

The central or main fault runs along the crown of the anticlinal from end to end. At its southern (visible) extremity it brings together the very lowest beds of the locality—the Glenkiln Shales—and the highest zone of the Hartfell division. As it passes to the northward it cuts obliquely across the *Glenkiln* beds and the lowest zone of the Hartfell Shales, and brings them into unnatural collocation with the variegated beds of the inferior portion of the Birkhill division.

The eastern fault runs approximately parallel to the central dislocation, letting in a long thin wedge of Upper Hartfell and Lower Birkhill beds between the main fault and the convoluted Upper Birkhill beds of the eastern cliff.

The western fault is of least importance. It is about 200 yards in length, attaining its maximum effect near its centre, where the truncated ends of the lower zones of the Birkhill Shales are seen in contact with the Barren Mudstones.

These three dislocations are all of the puzzling class known as inverted faults—the hade being towards the *upthrow* side of the break. Faults of this nature are numerous everywhere in the Moffat rocks; but the geologist is exceptionally fortunate in this district in the fact that the sections on the opposite sides of the break are easily interpreted, owing to the unmistakable characteristics of their component zones. These faults are miniature representatives of the gigantic dislocations of the Alleghanies of Pennsylvania and the Alpine regions of Europe. They resemble those of the latter area still further in the interesting circumstance that we have some examples of the well-known "fan-shaped" structure. In the Moffat district this is usually due to the fact that wedges of the inferior Glenkiln and Hartfell Shales have been pressed upwards, in the direction of least resistance, between converging walls of the natu-

rally overlying Birkhill and Gala beds, which have been forced inwards upon them from opposite sides by the excessive lateral pressure.

The section of the North Cliff in the present locality is a good instance of this phenomenon. The Birkhill Shales, which bound the central wedge of Hartfell Shales &c. included between the converging east and west faults, have been thrust inwards upon the lower and narrower portion of the wedge, forcing it upwards, and at the same time giving its component strata the characteristic radiating dip.

§ I. (B) *Description of the confirmatory sections of Craigmichan Scaurs.* (Plate XIII. Plan A.)

Before applying the results deduced from our study of the rocks of Dobb's Linn to the investigation of the shattered beds of the Moffat Series exposed along the various lines of black shale, it will be more satisfactory if we first put them to a crucial test by endeavouring to unravel at least one additional section in which the whole sequence of the beds is exposed. The only section suited for this purpose is that of Craigmichan Scaurs, which occurs on the western flank of Capel Law (2300 feet) at the head of Selcoth Burn, a small stream falling into the Moffat water about six miles below Birkhill.

The rocks of the Moffat Series at this locality are shown in a remarkably rugged gorge, about a mile in length, bounded on both sides by steep slopes, partly formed of naked cliffs of black shales, partly of mounds and trails of their weathered fragments. The southern wall of the gorge resembles that of Dobb's Linn. It is black and precipitous, but nowhere reaches a hundred feet in elevation. The northern wall is actually the flank of the mountain of Capel Fell, and shows a naked and almost vertical face of dark shale and mudstone, five hundred feet high, affording the most magnificent section of the Moffat Series in the south of Scotland.

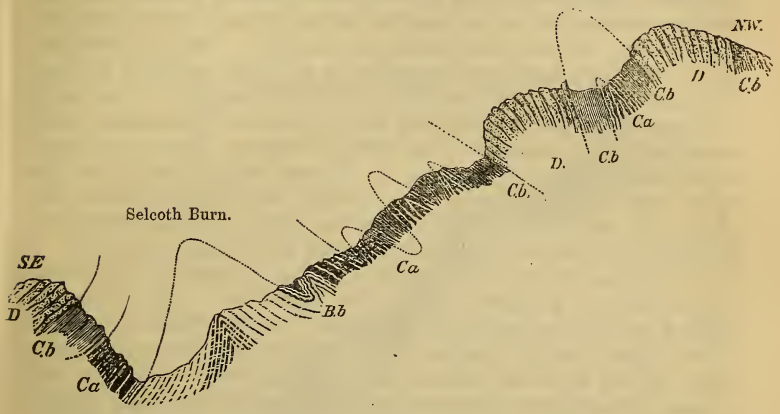
Everywhere within the gorge itself appear the black and variegated Moffat Shales. On the higher portions of the bounding cliffs are seen the thick greywackes and flagstones of the Gala group. At one spot the latter visibly descend the southern cliff for some distance, affording us an excellent starting-point from which to commence a study of the succession.

(a) *Section along line* A–B. (Fig. 2.)

Immediately we descend into the dark shales below the greywackes, we observe at a glance that we have no longer to deal with slightly disturbed and highly fossiliferous beds like those of Dobb's Linn, but with strata contorted and shattered, and so greatly altered that their fossils are almost wholly obliterated. Here and there, however, we observe certain grey bands with white lines dipping below the grits; and searching carefully right and left in the less

disturbed patches we detect the following species:—*Monograptus spinigerus* (Nich.), *M. Halli*, *Rastrites distans* (Lapw.), and *M. Hisingeri* (Carr.), all of which are strictly peculiar to the grey group or Upper Birkhill Shales of Dobb's Linn.

Fig. 2.—*Craigmichan Scaurs.* (Lower Section.)



D. Flagstones and greywackes of the Gala group.
Cb. Grey shales with black and white seams, contorted. *Rastrites maximus*, *Monograptus spinigerus*, *Diplograptus cometa*, &c.
Ca. Black carbonaceous flags and shales, with *Rastrites peregrinus*, *Monograptus gregarius*, *Diplograptus vesiculosus*, &c.
Bb. Pale mudstones and shales, non-fossiliferous.

In the beds immediately below no fossils are visible; but if we examine them in their extension higher up the stream, we see that they include the coloured lines of the *M.-gregarius* bands, together with some of the hard flag-like beds of the *D.-vesiculosus* zone; and yield in abundance such characteristic forms as *D. vesiculosus* (Nich.), *D. tamariscus* (Nich.), *D. palmeus* (Barr.), *M. gregarius* (Lapw.), *Rastrites peregrinus* (Barr.), &c.

This completes the section of the southern cliff. Crossing the bed of the stream and commencing the ascent of the northern slope, we pass over a great group of barren shales and mudstones of a greyish-brown colour, clearly the "Barren Mudstone" of our typical section, here, however, showing no trace of the fossiliferous *D.-anceps* seams. They are apparently nearly a hundred feet in thickness, more than twice that of their prototypes of Dobb's Linn. The cause of this is soon evident, as they are seen to be arranged in a sharp anticline, the axis of which is inverted, dipping slightly to the north-west.

To the Barren Mudstone succeeds a great mass of the Lower Birkhill Shales, much broken and twisted. It reposes upon the preceding zone at a low angle, exhibits the peculiar variegated mudstone lines, and yields an abundance of characteristic fossils. It subsides

in its turn below a shattered group of grey and black beds with white lines, affording *M. spinigerus*, *R. hybridus*, &c., the distinctive Graptolites of the Upper Birkhill Shales.

These finally plunge below a thick group of greywackes and flagstones, forming the upper portion of the cliff, and continued in a prominent series of bosses projecting along the hill-face to the right and left. The grits occupy about 100 feet of the section, and are visibly arranged in a synclinal form, the inverted axis of the fold dipping into the hill at an angle of about 40°. Beyond them the dark shales rise again to the surface in a hollow notch on the face of the steep slope above the actual summit of the cliff. The fossils of these shales are intermingled in the *débris* of the hollow; they are all of species peculiar to the Birkhill division. This notch shows at its summit the grey bands of the Upper Birkhill, which for the third time visibly pass below a superior mass of greywackes and shales. These form the small peak of the hill-top and are continuous with the great sheet of greywackes of the surrounding country.

It is obvious therefore that along this line of section the rocks of this locality are arranged in two main anticlinals. The strata exhibited range from the greywackes down into the Barren Mudstone of the Upper Hartfell Shales. Within these limits (exception being made of the apparent absence of the fossiliferous portion of the *D.-anceps* band), the sequence of rocks and fossils is precisely similar to that in our typical section of Dobb's Linn.

(b) *Description of the Section along line* B–D. (Fig. 3.)

Before we are able fully to comprehend the physical arrangement of the whole of the rocks exhibited within the Glen, it will be necessary to make a second traverse of the beds from the summit of the southern cliff along its southern margin.

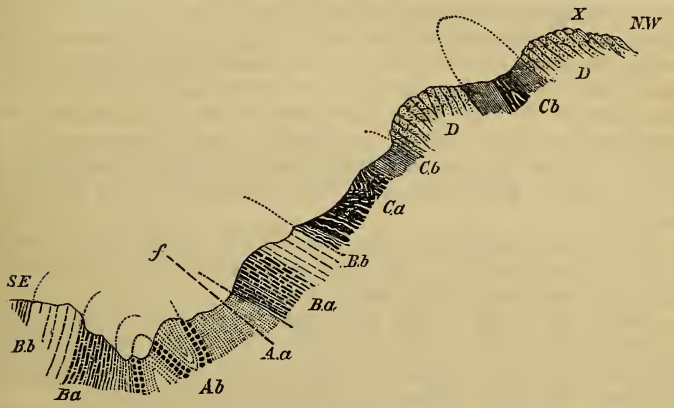
Descending the slope in a south-westerly direction from the point *X*, we pass over in succession the bands of grit and Birkhill Shales noticed in our former section to the line of the barren mudstone. This passes in a wide and very conspicuous pale-grey band transversely across the whole face of the cliff, reaching its southern edge at a point near the centre.

In our previous section this was the lowest bed exhibited. Here, however, we find a great thickness of subjacent strata. It is immediately underlain by a group of thin-bedded shales about 10 feet in total thickness, showing numerous white bands, especially in the upper part, and swarming with *D. Morrisi* (Hopk.), and *Pleurograptus linearis* (Carr.), thus agreeing exactly in stratigraphical position, mineralogical character, and fossils with our *P.-linearis* zone of Dobb's Linn.

This reposes upon a thickness of about 30 feet of contorted black flaggy shales with fragments of *Corynoides calycularis* (Nich.) and *Dicellograptus Forchhammeri* (Geinitz) in its upper beds, and showing at its base the hard thick-bedded and more siliceous bands of the *C.-Wilsoni* zone.

The remainder of the cliff down into the bed of the stream is occupied by strata wholly distinct in their general characters from any thing we have hitherto recognized in this locality. They consist of soft sandy mudstones, bluish grey, yellow, or even of a pure white, somewhat concretionary where unaltered, and reminding us strongly of ashy shales where indurated and slightly metamorphosed. With these are associated bands of hard siliceous rock, compact, ringing under the hammer, and weathering into cuboidal fragments.

Fig. 3.—*Craigmichan Scaurs.* (Upper Section.)



D. Greywackes and flags of the Gala group.
Cb. Grey shales, with *Rastrites maximus*, &c.
Ca. Black flags, with *Monograptus gregarius* and *Diplograptus vesiculosus.*
Bb. Grey mudstones, non-fossiliferous.
Ba. Black slaty shales, with *Leptograptus flaccidus, Dicellograptus Morrisi*, &c.
Ab. Black and grey shales, with *Didymograptus superstes, Thamnograptus typus*, &c.
Aa. Yellow and grey non-fossiliferous shales, with ribs and beds of hard siliceous flagstones.

These peculiar beds contain two bands of hard black shale, each about three feet in thickness. Some of the soft mudstone lines in them yield *Thamnograptus typus* (Hall), *Lasiograptus bimucronatus* (Nich.), *Dicranograptus ziczac* (Lapw.), &c. They therefore appertain to the same general group as our Glenkiln Shales of Dobb's Linn, the stratigraphical position of which is thus demonstrated to be below that of the Hartfell division.

These are the lowest beds exposed. They are broken by faults, and their interrelations complicated by some irregular contortions, so that it is difficult to arrive at any thing like a reliable estimate of their thickness. They give us, however, an excellent idea of the mineral characters of the Glenkiln group and of its great importance in the succession.

In all probability they are succeeded to the south by the overlying

Hartfell and Birkhill divisions; but no positive proof of this is obtainable, as the southern slope is gentle and overgrown with turf at this point.

(c) *Structure of the Glen.*

The evidence already collected is amply sufficient to enable us to determine the arrangement of the Moffat Series in this locality.

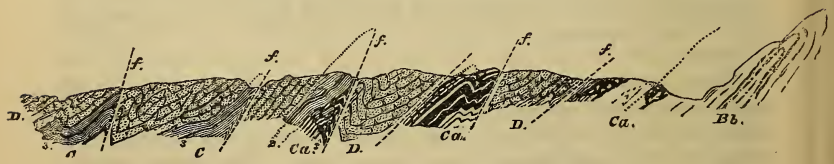
The strata are arranged in three parallel anticlinals. Of these the southerly one is by far the most important. Its axis runs in a straight line almost coincident with the bottom of the gorge. The level of this axis gradually declines to the west-south-west, so that newer and newer beds meet and cross over it as we proceed in that direction. The lowest beds exposed are the Glenkiln Shales, which occupy the bed and north bank of the stream, from the foot of the small burn entering from the north until they reach a point opposite the centre of the main cliff. Here they "nose in" upon the anticlinal, and the black beds of the Hartfell Series cross over one by one. They are followed in a similar manner by the "Barren Mudstone," through which the axis of the anticlinal runs to the foot of the cliff.

The second anticlinal exposes the Birkhill Shales in the hollow at the top of the cliff. The third exposes the *Rastrites-maximus* band in the greywackes beyond the summit.

Within the limits of the main cliff, as we have seen, the sequence is quite easy of comprehension; but in the streams to the north-east the contortion is so excessive that few beds are recognizable, and the various zones are inextricably intermingled.

Passing down the stream below the glen, however, an excellent section is visible (fig. 4), which enables us not only to completely confirm our former conclusions, but gives us a good idea of the dislocated character of the rocks of the neighbourhood.

Fig. 4.—*Section in Selcoth Burn.*



D. Purple and grey flagstones and graywackes.
C. Grey and purple shales with grey and black seams.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Black flags and shales with *Monograptus gregarius, Diplograptus vesiculosus*.
Bb. Pale mudstones, non-fossiliferous.
fff. Faults.

Along this line the Moffat Series emerges from below the greywackes in six distinct anticlinals. The axis of each of these arches is inverted, the degree of inversion gradually decreasing as we descend the course of the stream. With one doubtful exception each

of these anticlinals is a faulted one, a portion of the inverted leg of each being lost.

It is interesting to note how the degree and intensity of this inversion decreases in proportion as we pass outwards from the chief anticlinal line; and, as we shall see in the sequel, the section is an admirable illustration of the general structure of the whole of the Moffat district.

The beds exposed and their interrelations can be understood from the figure (fig. 4). The fourth anticlinal is the only one which calls for description in this place. Its strata, in addition to yielding all the fossils of the Lower Birkhill Shales, include also an almost unbroken mass of the Upper Birkhill beds. Their fossils are beautifully preserved, and embrace *Rastrites maximus*, *Monograptus turriculatus*, *M. Halli*, and other forms peculiar to the very highest band of the Birkhill Shales.

Conclusion.

It is evident from the preceding description that our conclusions regarding the sequence and fossils of the Moffat Shales, deduced from our study of the rocks of Dobb's Linn, are perfectly sound. The succession in the present locality is easily interpreted by their aid, and the inferiority of the shales and mudstones to the great greywacke group in which they are imbedded is amply demonstrated. We have here gained a much fuller insight into the thickness and lithological characters of the Glenkiln Shales, which are seen to have an importance which would never have been suspected from the insignificant exposure of these beds at Dobb's Linn, and we are now in a position to commence the study of the numerous black-shale bands of the district.

§ II. *Description of the Bands of Black Shale to the South of the Moffat-Yarrow Valley.*

(a) *Black Bands to the South-west of St. Mary's Loch.* (Plate XI., Map No. II.)

Nowhere in the Moffat district are the bands of black shale so continuous, their strata so little dislocated or confused, or their fossils so well preserved as in the high ground which lies to the south-west of St. Mary's Loch, and forms the watershed between the upper portion of the river-basins of the Ettrick and Yarrow. Four distinct black bands are here apparent, about half a mile apart, running approximately parallel with each other and with the main longitudinal valley to the north. Numerous streamlets descend the opposite slopes of the watershed, generally at right angles to the black-shale bands, but occasionally flowing over them for some distance. These furnish us in many instances with several exposures of the component strata of each band at different points along its course. In this way we obtain a large amount of confirmatory and supplementary evidence, which no one who is acquainted with the

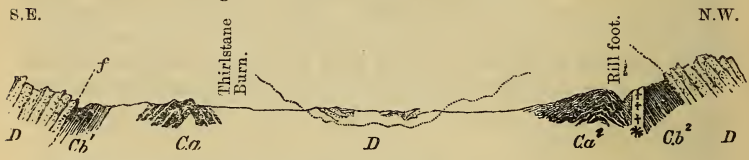
wrinkled and dislocated character of the Moffat rocks in any single exposure can fail to appreciate at its full value.

i. *First or Muckra Band.*

The most northerly of the black bands of this subregion runs parallel with the course of the upper Yarrow, from the immediate neighbourhood of St. Mary's Loch, crossing the watershed about midway along its course, and finally disappearing above the farm of Bodsbeck, opposite the central point of the Moffat valley.

Crossceuch (fig. 5).—Half a mile to the south-west of St. Mary's Loch this band crosses the small stream known as Whitehope Burn, a short distance above the farmhouse of Crossceuch. Here a little rill enters the burn from the east. At its mouth occurs an exposure of grey shales with black bands, traversed by a dyke of greenstone, but dipping steadily to the northward below the greywackes of the neighbourhood at an angle of about 45°. The presence of numerous white-clay bands in the grey and black beds enables us at once to identify them provisionally with the highest bands of the Birkhill Shales. This identification is fully verified by an examination of their included fossils, which embrace, among others, *Rastrites maximus* (Carr.) and *Monograptus Halli* (Barr.), forms strictly peculiar to the highest zone of the Birkhill Shales of Dobb's Linn.

Fig. 5.—*Section above Crossceuch.*



D. Flagstones and greywackes of the country.
Cb'. Grey and purple shales faulted and shattered. *Monograptus Hisingeri*,&c.
Cb². Grey shales, with seams of black and white mudstones, well bedded, containing *Rastrites maximus, R. hybridus, Monograptus spinigerus, M. Halli*, &c.
Ca. Black carbonaceous flags and shales, with *Diplograptus vesiculosus*, &c.
* Dyke of greenstone.
f. Fault.

Immediately to the south these shaly strata are underlain by convoluted black shales with *M. spinigerus* (Nich.), beyond which they are repeated and form the right bank of the stream for several yards. Passing over a few fragmentary patches of greywacke in the bed of the burn, indicative of the presence of a small synclinal, the Moffat Series again rise to the surface. At the foot of Thirlstane Burn, a few yards beyond, we come suddenly upon a boss of hard flaggy black shales, which both in appearance and stratigraphical position agree precisely with those at the summit of the *D.-vesiculosus* band of the Linn. They yield also its characteristic fossils, *D. vesiculosus* (Nich.) and *C. innotatus* (Nich.). They are succeeded to the south by isolated fragments of black rock showing the peculiar variegated lines of the *M.-gregarius* zone, and affording *M. tenuis, C. scalaris*, and others of its commoner fossils, and the section is closed by a

group of black, grey, and purple beds, faulted against the greywackes of the country to the south. These faulted beds yield *Monograptus spinigerus* (Nich.) and *M. Hisingeri* (Carr.), and are clearly a portion of the Upper Birkhill group.

Riskinhope Burnfoot.—Following the general direction of the band along its line of strike to the south-west, it is seen to cross the mound-like ridge of Peat Hill at a very oblique angle, and its strata are again visible near the mouth of Riskinhope Burn. Here the shales are too contorted and broken to enable us to make out the sequence; but the mineralogical characters and fossils of the central and more convoluted beds are recognizable as those of a portion of the Lower Birkhill group. The terminal strata are less shattered. They yield a few exquisitely preserved Upper Birkhill forms, and pass distinctly below the greywackes to the north at a high angle.

For the succeeding mile and a half, the position of the band is indicated by a peculiar road-like indentation in the smooth grass-grown flank of Muckra Hill. It arrests the drainage of the hill-slope and gives rise to a row of perennial springs.

Fig. 6.—*Section in Muckra Burn.*

D. Flagstones and greywackes of the Gala group. *Cb.* Contorted grey shales.
Cb^3. Grey shales with black and white seams, containing *Rastrites maximus*, *Monograptus Halli*, &c.
Cb^2. Grey shales with black bands and seams of white clay, with *Monograptus spinigerus*, *M. Clingani*, *M. Hisingeri*, trails of Annelids, nodular concretions, &c.
2. Horizon of *Monograptus spinigerus*. 3. Horizon of *Rastrites maximus*.
Ca. Black flagstones and shales, greatly shattered, non-fossiliferous.
Bb. Pale flaggy mudstones and shales.
f. Fault.

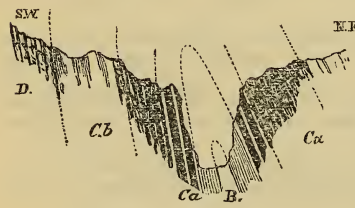
Muckra Burn (fig. 6).—The second important exposure of the rocks of this band is met with in the Muckra Burn, which is crossed obliquely by the dark shales at a point about midway along its length. As in the former instances the beds in the southern (or inverted) portion of the exposure are so shattered and altered that their detailed identification is well-nigh impossible. There is, however, enough visible to enable us to assure ourselves of the fact that they are actually arranged in an anticlinal form. The central beds resemble the "Barren Mudstones" of the Hartfell Shales. They are followed on both sides by black beds which come into the place of the Lower Birkhill Shales. These are succeeded, in their turn, by the grey and black beds of the Upper Birkhill, which to the south are visibly in conformable contact with the greywackes.

The structure of the northern half of the exposure, however, is perfectly clear. Its beds are those of the grey division of the Birkhill Shales, much convoluted and fractured, but very slightly altered.

They form two subsidiary and partly broken anticlinals, and the highest beds pass visibly beneath the greywackes to the north. Strata belonging to the *D.-cometa*, *M.-spinigerus*, and *R.-maximus* zones are exposed here and there, and fossils are abundant and well preserved. The white lines of the highest division are very conspicuous, as are also the inferior bands of grey sandy mudstone and shivery shale, with their characteristic Annelide-trails and concretions. The commonest fossils are *Rastrites maximus* (Carr.), *R. capillaris* (Carr.), *Diplograpsus palmeus* (Barr.), *Monograptus Halli* (Barr.).

Black Grain.—Proceeding to the south-westward, the band next crosses the watershed into the basin of the Ettrick, where its rocks are first visible in a small score near the head of Black Grain. Here, although the beds are highly metamorphosed and wholly unfossiliferous, their steady dip and the distinctness of the mineral characters of the various zones, enable us to recognize the chief subdivisions at a glance. The Barren Mudstones of the Hartfell series occupy the centre of the exposure. To the south they are covered by the black flags and shales of the Lower Birkhill; and the exposure is closed by the more recent grey and black shales with white-clay bands, which dip steadily under the greywackes to the south at an angle of about forty degrees.

Fig. 7.—*Generalized Section across Fala Grain.*



D. Greywackes and flagstones.
Cb. Grey flaggy shales with black and white seams.
Cα. Hard black flags and shales, with seams of variegated mudstone. *Diplograptus vesiculosus, Monograptus gregarius.*
B. Pale non-fossiliferous mudstones.

Fala Grain (fig. 7).—This reading of the sequence is confirmed by the beautiful section visible in Fala Grain, a small burn descending the southern slope of Herman Law. In the lower portion of its course the bed of this stream coincides with the general direction of the black-shale band under description, and the Moffat strata are admirably exposed in the steep cliffs on its banks. The first beds visible to the north-east are grey and black shales with a northerly dip. These are underlain by the main mass of the zones of *M. gregarius* and *D. vesiculosus*, whose variegated and hard flag-like strata form the walls of the gorge for a distance of nearly 200 yards. A great thickness of barren grey mudstone succeeds, and probably forms the lowest stratum exposed. To the south the dark shales and flags reappear, and, as before, in an almost vertical attitude. Near the foot of the stream the section is completed by the grey and black shale group with the usual white-clay bands, in conformable contact with the greywackes to the south, conspicuously displayed in the hill-face to the left.

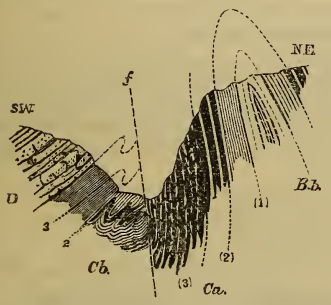
The distinctive fossils of the Lower Birkhill Shales may all be collected at this locality. The upper subdivision is too much broken and altered to yield more than a few rare specimens.

It is needless to follow this band in its prolongation to the south-west. The exposures already examined amply demonstrate that in this district there are no beds in the rocks of the band that are not visible in our typical section of Dobb's Linn. Wherever the succession from the shales into the greywackes is unbroken, the latter are immediately underlain by the representatives of our highest Birkhill bands, below which occur in their natural order the subjacent strata of our typical locality.

Thirlstane Burn. (Plate XIII. Plan B.)

Midway between the first and second of the black-shale bands, an excellent local exhibition of a portion of the Moffat series occurs at the head of a small stream falling into Thirlstane Burn (fig. 8).

Fig. 8.—*Section at Thirlstane Score.*



D. Purple flagstones and flaggy shales.
Cb. Grey shales with seams of black, yellow, and white mudstones.
3. Horizon of *Rastrites maximus*, *Monograptus Halli*, &c.
2. Horizon of *Monograptus spinigerus* (= *Sedgwicki*).
Ca. Black flags with partings of variegated mudstones, &c.
(3) Zone of *Monograptus gregarius*. (2) Zone of *Diplograptus vesiculosus*. (1) Zone of *D. acuminatus*.
Bb. Pale and non-fossiliferous mudstones.
f. Fault.

The shales are first visible about midway along the course of the last-named stream, but the section at that spot is valueless for purposes of comparison. At the head of the tributary burn the whole sequence of what are instantaneously recognized as the Birkhill Shales is visible, from the green mudstone of the *D.-anceps* band into the greywackes.

A fault traverses the beds obliquely from south to north, and this is crossed at a very acute angle by a subordinate anticlinal line, a little below the greywackes. To the west of this anticlinal the beds are in their natural position; to the east they are slightly inverted.

The *D.-vesiculosus* band forms, as usual, a steep cliff and yields its peculiar fossils in abundance. The *M.-gregarius* zone with its variegated and nodular seams is seen in the sides and base of the cliff, the coloured lines being especially conspicuous in some small bosses on the floor of the score. The grey and black beds of the Upper Birkhill group form both sides of the little anticlinal already re-

ferred to, and their lower beds are much broken up along its course. The *M.-spinigerus* zone, however, is easily identified, exhibiting the peculiar aluminiferous black shales, with their excess of pyrites, their slightly concretionary structure, and their beautifully preserved examples of *Monograptus spinigerus* (Nich.). The highest or *R.-maximus* zone of the Upper-Birkhill Shales is here even more satisfactorily exposed than at Dobb's Linn. Many of the mudstones are of a deep purple colour, but all show the characteristic white and yellow lines and thin seams of dark shales, loaded with Graptolites in a state of high relief.

These beds pass under the greywackes at a low angle near the head of the score, where the overlying beds are seen to be much thinner and more flag-like than at Dobb's Linn.

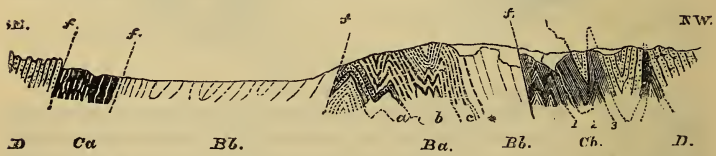
The opposite leg of the chief anticlinal is hidden below the turf: some hardened black shales projecting from the hill-side below possibly belong to it.

Every fossil of the Birkhill series of our typical section may be collected in the corresponding zones of this locality. Those detected and noted by myself will be found in the lists given in the second part of this Memoir.

ii. *Second or Riskinhope Band.*

Moory Syke.—The finest section of the deposits included in the second band of the black shales is met with near the eastern extremity of the band. It occurs in the course of the small stream known locally as the Moory Syke, at a point about half a mile to the south of the Thirlstane score (fig. 9).

Fig. 9.—*Section at the head of Moory Syke.*



D. Greywackes and flagstones, grey and purple, with partings of flaggy shale.
Cb. Grey, purple, and yellow shales, with seams of black mudstones and white-clay lines, containing *Rastrites maximus, Monograptus Halli, Diplograptus folium*, &c.
1. Seam of *Monograptus Clingani*. 2. Horizon of *Monograptus spinigerus*. 3. Horizon of *Rastrites maximus*.
Ca. Black carbonaceous flags and shales, with partings of variegated clays, containing *Diplograptus vesiculosus, Monograptus gregarius*, &c.
Bb. Pale grey and green non-fossiliferous mudstones.
* Fossiliferous seam in ditto.
Ba. Black slaty flags and shales, with seams of white mudstones in *c*.
a. Zone of *Pleurograptus*. *b*. Zone of *Dicranograptus Clingani*. *c*. Zone of *Climacograptus Wilsoni*.
fff. Faults.

To the north of the chief exposure at this locality two preliminary anticlinals display a few feet of the grey-shale group, exhibiting the

peculiar white-clay seams, and affording some characteristic fossils. In the main section the grits of the district are seen to repose, at an angle of about 60°, upon the grey and white-lined shales of the *R.-maximus* zone. The component beds of this zone are by no means so satisfactorily exhibited as in Thirlstane Syke; but the characteristic fossils are abundant. Its strata lie in their natural order upon an excellent section of the dark and pale shales of the zone of *M. spinigerus*. Here we recognize immediately the peculiar black pyritous mudstones, with their beautifully preserved examples of *M. spinigerus*, *M. Hisingeri*, &c., and the accompanying grey and yellow sandy shales with their strange reticulations, so strikingly characteristic of the zone at Dobb's Linn.

Below the *M.-spinigerus* seams the shales are much contorted; but, running as a continuous bed among them, zigzag fashion, we notice with much interest the extraordinary "*Clingani*" band of our typical section. It is here nearly a foot in thickness, and is crowded with well-preserved examples of *Monograptus Clingani* (Carr.) and *M. leptotheca* (Lapw.). These Upper Birkhill beds are faulted immediately against the "Barren-Mudstone" zone of the Upper Hartfell Shales, the whole of the Lower Birkhill beds being missing from this spot. The "Barren Mudstone" reposes in its natural order upon a distorted mass of the slaty black shales of the Lower Hartfell group. The highest or *Pleurograptus* zone of the latter is remarkably conspicuous, being repeated again and again in the section. It yields a few of the characteristic fossils, and shows many of the soft white sandy mudstones, which are here much thicker than at Dobb's Linn.

The inferior *D.-Clingani* and *C.-Wilsoni* zones occur in the abrupt arches below. Their beds are almost destitute of fossils; the chief forms obtainable are *Dicranograptus ramosus* (Hall), *Dicellograptus Forchhammeri* (Gein.), *Diplograptus foliaceus* (Murch.), *Corynoides calycularis* (Nich.), &c., an association sufficient to place beyond doubt our determination of their place in the succession.

They are faulted at their southern termination against a long convoluted sheet of the "Barren Mudstone," which is very indifferently shown in the bed of the stream. This is followed by a portion of the *D.-vesiculosus* band of the Lower Birkhill group, dipping to the south and overlain by a fragment of the variegated *M.-gregarius* zone with *Monograptus gregarius*, *M. lobiferus*, &c. The latter is finally faulted abruptly against the neighbouring greywackes.

Earl's Hill.—From the Moory Syke the black-shale band passes to the south-westward over the crest of Earl's Hill. In the deep notch in the ridge a good exposure of its beds may be examined. The faulting and contortion so conspicuous in the preceding section are here continued and greatly intensified. The central beds of the *M.-gregarius* zone are visible to the right, marked by the presence of *M. lobiferus* (M'Coy) and *M. tenuis* (Portl.). They are faulted against the white-banded zone of *Pleurograptus linearis*, which in the floor of the score yields good examples of its most characteristic fossil forms, *Pleurograptus linearis* (Carr.), *Amphigraptus divergens*

(Hall), *Leptograptus flaccidus* (Hall), *Diplograptus quadrimucronatus*. To the left the strata are excessively metamorphosed and are of a deep purple colour; those to the extreme south-west appear to belong to the Glenkiln group.

Riskinhope Burn (fig. 10).—Passing over the very indifferent exposure of the strata of this band in the glen of the Whitehope Burn, we cross the succeeding ridge into the higher portion of the hollow valley of the Riskinhope. This little stream runs generally along the strike of the dark shales, and affords many small sections in its banks. In the lowest of these sections we have a full exhibition of the zones of *D. vesiculosus* and *M. gregarius*, the flag-like strata forming the bounding walls of the stream-bed for some distance, and clearly arranged in a distinct anticline.

Higher up the stream an ascending section may be traced through all the succeeding Birkhill zones into the grey flags of the *R.-maximus* band, the strata dipping to the south in their natural order. Some little distance beyond, a similar succession can be made out on the north leg of the anticlinal. The miniature cliffs which next form the south bank of the stream expose a continuous section of the contorted bands of the Birkhill Shale. Especially conspicuous are the peculiar greenish-yellow beds of the zone of *M. spinigerus*, with their Annelid-trails and characteristic superficial reticulations. Beyond them the white-lined flaggy shales of the *R.-maximus* band abound, and are seen to be in irregular contact with the greywackes, which here form a portion of the southern bank. At the head of the gully the grey and black beds again emerge and yield well-preserved fossils of the *R.-maximus* band. All the strata described clearly form portions of a single anticlinal, the axis of which crosses the stream at a very oblique angle, about 200 yards above the point where the dark shales are first apparent.

To the south the greywackes last mentioned are faulted against the following succession :—

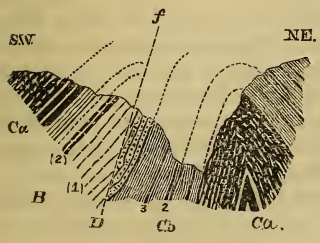
Greenish-grey shivery mudstones (S. at 60°)	5 feet.
Dyke of zeolitic trap	8 feet.
Thick-bedded black flags and shales with *D. vesiculosus*, *M. gregarius*, &c.	20 feet.

This can only be interpreted as the southern side of a second anticlinal, faulted along the summit of the arch, the dyke of trap coming into the place of the *D.-anceps* band of the Upper Hartfell Shales.

A hundred yards beyond the section last noted, and in the line of strike of its component beds, we meet with the missing *D.-anceps* zone in a small score in the hill-side to the south. It is imbedded in a convoluted mass of slightly altered "Barren Mudstone." The peculiar soft black seams of the zone are easily identified and yield (as usual in a state of partial relief) its conspicuous species *Dicellograptus anceps* (Nich.), *Diplograptus truncatus* (Lapw.). The general arrangement of the dark shales in the glen will be understood on an examination of the following section (fig. 10), in which all the foregoing facts are generalized.

In the prolongation of the strike to the south-west we reach a second score, which affords a section completely verifying our view

Fig. 10.—*Riskinhope Burn.* (Generalized Section.)



D. Flagstones and greywackes, contorted.
Cb. Grey shales with black and white seams.
3. Horizon of *Rastrites maximus.*
2. Pyritous shales with *Monograptus spinigerus* &c.
Ca. Black flaggy shales visible in large anticlinal in lower portion of the gorge.
B. (1) Grey and green mudstones.
(2) Soft black shales with *Dicellograptus anceps*, seen in scores above the head of the burn.
f. Fault.

of the attitude and sequence of the beds. The strata exposed all dip steadily to the southward at about 60°, in the following (descending) order :—

(*c*) Steep cliff formed of the hard flags and shales of the *D.-vesiculosus* and lower *M.-gregarius* bands, yielding *D. vesiculosus, M. gregarius, M. attenuatus*, &c.	30 feet.
(*b*) Soft grey and green mudstones with black bands (clearly the zone of *Dicellograptus anceps*, &c.)	20 feet.
(*a*) Soft shivery barren mudstones, grey and green	20 feet.

Above the section the scattered fragments of shale lying on the hill-slope prove the presence of the grey and white-lined Upper Birkhill Shales at this point. The summit of the ridge is formed by the greywackes of the country.

The Yellow Mire.—Following the line of depression marking the place of the Black Band over the little watershed, we reach a broad peat-clad hollow, drained by several small feeders of the Muckra Burn. This hollow owes its origin to the extraordinary expansion of the band of easily eroded black shales at this locality, where its maximum diameter probably exceeds a quarter of a mile. The yellow and iron-stained fragments of the "Barren Mudstones" and the overlying shales are exposed here and there along the courses of all the little rills that wander through the moss, giving to the spot its quaint but characteristic title of the Yellow Mire.

Along the northern margin of the band lie the Birkhill Shales. The upper and greyer division of the group is alone exposed. Its strata are much contorted, but are comparatively unaltered. They contain in abundance the characteristic fossils of the *R.-maximus* zone, which are found in good preservation in the grey shales immediately in contact with the greywackes at the point where the eastern arm of the Muckra Burn emerges from the moss.

None of the forms proper to the Lower Birkhill Shales are obtainable, the inferior portion of the Birkhill group being apparently represented, in part, by a thin and excessively crumpled band of dark

flagstones interposed between the Grey Shales and the Barren Mudstone. It lies approximately along the general course of the main line of fault that runs along the strike from the Wisp to Brockhope Burn, and which for several miles has placed a narrow seam of greywacke in the geographical centre of the band, dividing it into two parallel lines of black shales.

In some shallow scores in the middle of the Yellow Mire there are some indifferent exposures of the central, and therefore oldest, beds of the band. The deepest bed visible is the *Pleurograptus-linearis* zone of the Upper Hartfell Shales. The black thin-bedded shales of the zone with their white lines admit of immediate identification. Fossils are rare; *P. linearis* (Carr.) and *Leptograptus flaccidus* (Hall) are both present. The white band at the summit of the zone is very conspicuous, as are also the shivery mudstones of the Barren beds.

Of the southern leg of the anticlinal at this locality we know very little; a few Birkhill forms may, however, be collected from the scattered fragments of shale to the south of the scores. The strata themselves are all hidden from sight by turf and moss.

iii. *Third or Whitehope Band.*

Whitehope Burn (fig. 11).—This band attains its greatest diameter near the small cottage of Whitehope, to the west of Earl's Hill, where a tolerably continuous transverse section is visible in the course of the

Fig. 11.—*Section below Whitehope Cottage.*

D. Flagstones and grits.
Cb. Grey shales with black bands, yielding *Monograptus Halli* in relief.
Ca. Black pyritous flags with seams of variegated mudstones. *Monograptus gregarius, Rastrites peregrinus*, &c.
f. Fault.

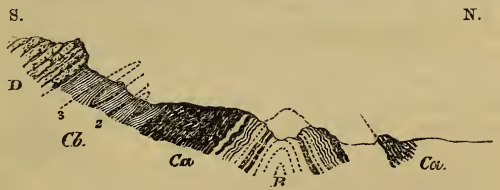
stream below the cottage. Near the northern edge of the band a thin group of grey shales with black seams, yielding *Monograptus Halli* (Barr.) and *Rastrites maximus* (Carr.), subsides below the greywackes to the northward at a gentle angle. The presence of these beds at this point is due to a small arch of the strata, above which the greywackes pass unbroken in the steep hill-face to the left, descending again to the level of the bed of the stream to the south. The most northerly strata of the main anticlinal which are actually visible occur at the angle of the stream some distance beyond, where there is a boss of crumpled Lower Birkhill flaggy and carbonaceous shales containing fragmentary examples of *Monograptus lobiferus* (M'Coy) and *M. gregarius*. Similar beds, greatly disturbed, but clearly associated with grey shales, succeed, and are irregularly

exposed as far as the foot of Easter Burn, much of the section being buried under clay and boulders. The remainder of the traverse is formed of the various zones of the Birkhill Shales, from the *D.-vesiculosus* band to that of *M. spinigerus*. They are capitally shown in the banks of Easter Burn, and afford an abundance of Graptolites, especially of those of the zone of *M. gregarius*, the peculiar variegated strata of which are very conspicuous in several small quarries on the left of the stream. The deepest beds exhibited are greatly disturbed; but the strata gradually assume their natural position towards the southern margin of the band, where a few of the highest grey-shale beds are cut out by a small fault at their point of contact with the greywackes.

This single section might perhaps be regarded as affording sufficient proof of the identity of the strata of this band with the Moffat beds already described, and of their corresponding inferiority to the greywackes. The evidence is defective, however, in demonstrating the presence of any thing older than the Birkhill Shales, and in defining the relation of the latter to the greywackes to the south.

Black Grain (Plate XIII. Plan C; fig. 12).—These missing links in the chain of evidence are both supplied by a remarkable section of the rocks of the band in Black Grain, a small stream descending the opposite slope of the watershed, about two and a half miles to the south-west of Whitehope. Between the two localities the band can be traced almost continuously by the usual N.E. and S.W. depression due to its presence, as well as by the occasional exposure of the characteristic shales and mudstones along its course.

Fig. 12.—*Black Grain.* (Sketch Section.)



D. Cliff of purple flagstones.
Cb. Grey and purple shale, with black and white seams.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Hard black flags and shales.
B. Contorted pale mudstones with black seams.

In Black Grain the greywackes of the country dip outwards from the margins of the band, both to the north and south. To the north the succession is unintelligible. To the south the greywackes form the summit of a steep cliff, which here causes an abrupt deflexion of the stream-course. They visibly overlie a great thickness of grey and purple shales, containing black seams and thin lines of white and yellow clay.

These are clearly the Upper Birkhill Shales. They yield in abundance the characteristic fossils *Rastrites maximus* (Carr.) and *Mono-*

graptus Halli (Barr.), but are at first sight apparently much thicker than usual, the result of several small inverted folds.

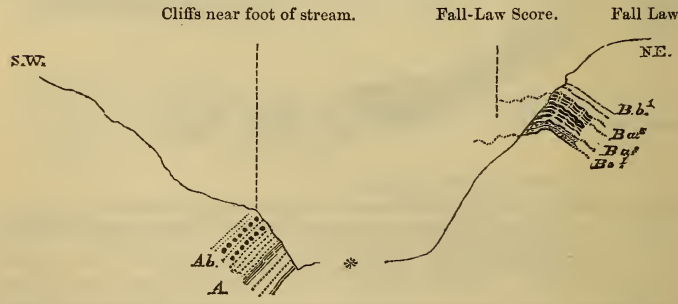
In the lower portion of this grey group we find a tolerably complete exhibition of the *Monograptus-spinigerus* or *Sedgwicki* zone. Some of its most prolific beds at this locality occur on the north bank of the stream, opposite the base of the cliff.

In the main section they are brought down by a small fault against the zone of *Monograptus gregarius*, prominent by its peculiar variegated clays. This reposes upon the hard black flags of the zone of *Diplograptus vesiculosus*, which stand up almost on edge in gnarled rugged bosses on both sides of the stream. In the sloping bank on the left of the stream several deep scores expose sections of the underlying black and green shivery mudstones of the *Dicellograptus-anceps* zone of the Upper Hartfell Shales. They are charged with *Dicellograptus anceps*, *Diplograptus truncatus*, &c., and are arranged in several converging folds, piercing the *D.-vesiculosus* flags like a gigantic wedge.

iv. *Fourth or Berrybush Band.*

Berrybush Burn (fig. 13).—The fourth and most southerly band of black shale in this district attains its easternmost extension in the deep valley drained by the small burn of Berrybush. Midway along the course of the burn the steep flank of the mountain of Fall Law, which bounds the valley to the northward, is gashed by a deep score dug out of the tractable shales and mudstones of the Moffat Series, whose convoluted beds cross it almost at right angles to its general direction.

Fig. 13.—*Berrybush Burn.* (Sketch Section.)



Ab. Bands of thin-bedded slaty shales, imbedded in shivery mudstones, containing *Cœnograptus, Didymograptus, Thamnograptus.*

A. Thick beds of pale mudstones and shales, with seams and ribs of hard grey rock, non-fossiliferous. (Vertical Section II. fig. 26, p. 304.)

*Bb*¹. Pale non-fossiliferous mudstones, well-bedded.

*Ba*³. Slaty shales, with *Diplograptus quadrimucronatus.*

*Ba*², *Ba*¹. Black flaggy shales, much contorted, containing *Dicranograptus ramosus*, &c. * Space omitted.

At the summit of the score the " Barren mudstones " of the Upper

Hartfell Shales plunge into the grass-grown hill-face at a steep angle. They visibly repose upon the thin-bedded shales and white mudstones of the *Pleurograptus* zone, which affords abundant, but miserably preserved examples of such characteristic fossils as *Leptograptus flaccidus* (Hall) and *Diplograptus quadrimucronatus*. Below, the walls of the score are formed of the thicker-bedded black flags of the zone of *Dicranograptus Clingani*, which undulate in numerous irregular folds, and yield a few fragmentary specimens of their peculiar species *D. Clingani* and *Climacograptus caudatus*. The deepest beds visible are the black, flaggy, and flake-like beds of the zone of *Climacograptus Wilsoni*, in which the only fossils apparent are the characteristic *Discina* and fragments of sponges. The remainder of the descent into the bottom of the glen is obscured by the débris washed out of the score.

That the strata thus hidden from observation are those of the naturally subjacent Glenkiln Shales is at once made evident if we descend the main stream for a short distance. About 200 yards below the foot of the score we encounter a grand group of sections of the beds of that division, all dipping steadily to the southward, at an angle of about 60°, into the face of the steep ridge on the right of the burn.

No one who has examined the Glenkiln beds of the symmetrical section of Craigmichan Scaurs, where their inferiority to the Hartfell and Birkhill divisions is so unmistakably exhibited, can hesitate to identify with them all the strata exposed in these sections. We have the same peculiar yellowish-grey and white mudstones, here concretionary or shivery and iron-stained, there flaggy and riddled by innumerable burrows of Annelides; the same thick-bedded grey seams of siliceous rock, weathering like ribs of flint; and the same hard but easily disintegrating bands of black shale, conspicuous in the light-coloured mass in which they are intercalated. They are here, however, much less altered than at Craigmichan; there is no direct proof of their repetition by fold or fracture, and at the same time they are all in such a position as to admit of complete study.

The largest sections occur near the foot of the burn. In the second of these the succession is exhibited which is tabulated on fig. 26, p. 304.

This is one of the most satisfactory sections of the beds of the ribbed-shales group of the Glenkiln division exposed within the limits of the Moffat district. Its strata lie at gentle angles, are quite unaltered, and admit of thorough examination *in situ*.

The fossils of the included black-shale bands embrace a large majority of peculiar Glenkiln forms, chiefly *Didymograptus superstes* (Lapw.), *D. serratulus* (Hall), *Cœnograptus gracilis* (Hall), *C. surcularis* (Hall), *C. explanatus* (Lapw.), *Dicranograptus ziczac* (Lapw.), *Dicellograptus sextans* (Hall), *Diplograptus bimucronatus* (Nich.).

These beds occupy the centre of the band, which at this place is inferred to be about 200 yards in diameter. To the north, as we have seen, they are surmounted by a complete development of the

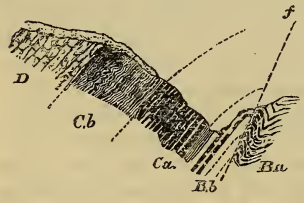
Lower Hartfell Shales. To the south the ground is covered with vegetation, and none of the Moffat shales are visible.

Cowans Croft, &c.—Following the band to the south-west above the head of the valley, we observe that its great lateral extension gives rise to a wide peat-covered flat, like that of the Yellow Mire. It is crossed near its eastern extremity by the "Captain's Road," an almost obliterated mountain-track between Crosscleuch and the valley of the Ettrick. In this track, and the little quarries and scaurs in its neighbourhood, fragments and even bedded patches of the Hartfell and Birkhill shales are discernible on both sides of the central portion of the band.

Additional evidence of the presence of the Birkhill Shales may be gathered at intervals along the sloping hollow followed by the band to the south of the summit of Ramsey Knowe. In this direction the band rapidly contracts its diameter to one fourth of that which it possessed at the head of Berrybush.

Scabcleuch (Plate XIII. Plan D).—Crossing the watershed into the hollow drained by the stream of Scabcleuch, a small tributary of the latter descends the western side of Ramsey Knowe exactly in the line of the black-shale band. This has worn a little gorge, known as "The Slunk," out of the mossy slope, and has laid bare an admirable exposure of the junction of the beds of the black band and

Fig. 14.—*Section across the Slunk, Scabcleuch Burn.*



D. Greywackes much contorted, seen at stream foot.
Cb. Grey shales with black and white bands, contorted, non-fossiliferous.
Ca. Well-bedded black flags and shales with partings of variegated mudstones. *Monograptus gregarius, D. vesiculosus*, &c.
Bb. Pale mudstone with seam of black shale.
Ba. Shattered black slaty shales with *Pleurograptus.*
f. Fault.

the greywackes to the south (fig. 14). Hitherto, beyond the detection of a few fragments of the higher Moffat Shales near the southern margin of the band, we have obtained no positive proof of the presence of the Hartfell and Birkhill shales to the south of its longitudinal axis. In this exposure that proof is complete and decisive. The deepest beds seen to the north, towards the centre of the band, form a portion of the *Pleurograptus* zone of the Lower Hartfell Shales, yielding *Leptograptus flaccidus* (Hall), &c. They are in irregular contact with a broken mass of the "Barren Mudstone," beyond which certain black, yellow, and grey bands, that represent the *D.-anceps* zone, plunge visibly beneath the shivery mudstone with *Diplograptus acuminatus*, which forms the base of the Birkhill Shales. Upon this reposes 9 feet of hard thick flags (clearly the *D.-vesiculosus* zone), yielding the characteristic fossils *Diplograptus vesiculosus* (Nich.), *Monograptus tenuis* (Portl.), &c. This subsides below a thick mass of thinner flags, with bands of variegated mud-

stones, red, yellow, and blue, affording in its lower portion *Monograptus gregarius* (Lapw.), *M. cyphus*, (Lapw.), &c., and in its higher beds *Rastrites peregrinus* (Barr.), *Monograptus communis*, &c.

The foregoing strata dip to the south at 45°–60°, and near the foot of the stream the succession is closed by a group of grey and black shales with white lines, clearly the Upper Birkhill beds, which pass beneath the greywackes of the district to the south.

Shiel Syke.—A small and indifferent section on the opposite side of the hollow to the south-west affords evidence of a further contraction of the band. It exhibits merely a few feet of the *D.-vesiculosus* zone and a portion of the highest Grey-Shale group, dipping to the north—enough, however, to prove the presence of the Birkhill shales to the north of the axis of the band.

Cossar-Hill Burn.—In Cossar-Hill Burn a few shattered and highly indurated black beds are all that remain to represent the Berrybush band, and in the next valley it seems altogether to disappear below the contorted greywackes.

Summary.

At this stage, therefore, our study of the strata exposed in the four uninterrupted black-shale bands to the south-west of St. Mary's Loch has established the following propositions:—

(i.) The sequence, lithological characters, and peculiar fossils of the subgroups of strata included within these bands are identical in every respect with those of the various zones of the Moffat series as exposed in our typical section at Dobb's Linn.

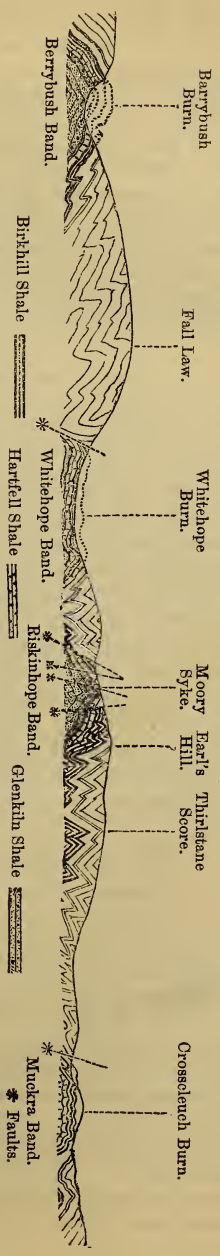


Fig. 15.—*General Section through the district to the south-west of St. Mary's Loch.*

(Scale 4 inches to 1 mile.)

(ii.) The oldest and deepest beds of each black-shale band occur almost invariably in its central portions; and, where the succession is unbroken, those of the highest and most recent zone graduate upwards on both margins of the band into the basal beds of the surrounding greywackes.

These facts point unmistakably to the conclusion that the four parallel black-shale bands of this locality are formed by a repetition of one and the same great group of black shales, and that these owe their recurrence, not to the presence of a series of gigantic faults, but to several parallel folds of the strata. In other words, the rocks of the Moffat Series are the oldest deposits in this area, being inferior in stratigraphical position to the barren greywackes, through which they rise in anticlinal forms (see fig. 15).

That these relationships hold good everywhere to the south of the Moffat valley will next be demonstrated.

(b) *Black Bands in the Valley of the Yarrow.*

To the north-east of the area last described there are several exposures of the shales and mudstones of the Moffat series. From their position, and from the attitude of the greywackes with which they are associated, there is a strong presumption that they rise to the surface in the prolongations of the anticlinals already noted. No direct evidence, however, is forthcoming upon this point, as the rock-sections are restricted to the miniature cliffs formed by a few of the small upland streams, and the intervening country is covered by turf, gravel, or peat. In the majority of the exposures the strata are too much shattered, or too imperfectly exhibited, to allow us either to give their original sequence or their present relations to the surrounding greywackes. There are, however, two exceptional sections at the extreme north-east of the area, in which the evidence upon the second of these points is distinct and unequivocal.

i. *Mount-Benger Burn* (fig. 16).—The finest exposure in this direction is afforded by the small stream which derives its title from

Fig. 16.—*Section in Mount-Benger Burn.*

D. Flaggy greywackes and thin grits and shales.

Cb. Purple and grey mudstones with seams of black shales and white clays, containing *Rastrites maximus, Monograptus Halli,* &c.

Ca. Contorted flaggy black shales with variegated partings. *Diplograptus palmeus, Monograptus triangulatus, M. gregarius,* &c.

Ba^3. Well-bedded black slaty shales, highly fossiliferous, with *Pleurograptus linearis* &c.

Ba^2. Shattered black flaggy shales, with *Dicranograptus ramosus* &c.

* Space omitted. *f f.* Faults.

the farmhouse of Mount Benger, once the residence of Hogg, the Ettrick Shepherd. It occurs at the side of the high road between the town of Inverleithen and the valley of the Yarrow, about half a mile above the mouth of the burn.

Here the greywackes of the country are exposed in several large quarries in the hill-side, and with few local interruptions are seen to dip steadily to the north-west at high angles. Where a small fence crosses the burn, the highest beds of the dark-shale series emerge from below them in a similar attitude.

The first beds apparent are grey, green, and purple mudstones, in which are intercalated two groups of black-shale bands, with seams of white clay. They are much softer than usual, but otherwise present all the peculiarities of the *R.-maximus* zone of the Birkhill Shales. The fossils they contain are beautifully preserved; the characteristic forms *Rastrites maximus*, *Monograptus Halli*, and *Retiolites perlatus* are especially abundant.

Below the *R.-maximus* zone the talus obscures the section for several yards, and the next strata visible are hard, black, slaty flags of a couple of inches in thickness, barren of fossils except upon two or three horizons. They are clearly a portion of the zone of *Dicranograptus Clingani* of the Lower Hartfell Shales. In addition to *Dicranograptus ramosus* and *Dicellograptus Forchhammeri*, *Siphonotreta micula* (M'Coy) is perhaps their most abundant fossil.

Beyond this point a badly exposed and greatly shattered section marks the position of faulted beds. Next succeeds a group of soft, slaty, black shales, containing in its higher portions several seams of white mudstone, and recognizable at a glance as the zone of *Pleurograptus linearis*. Its beds are almost flat, and are unbroken and unmetamorphosed. They swarm with the characteristic fossils of the zone, all of which are in excellent preservation. The most striking species obtainable are *Pleurograptus linearis* (Carr.), *Amphigraptus divergens* (Hall), *Dicellograptus elegans* (Carr.), *Diplograptus quadrimucronatus* (Hall).

For the next hundred yards the stream flows over alluvium and boulders, and the terminal beds of the section are met with at the foot of a small rill which enters from the north.

Here there is an exposure of the greater number of the zones constituting the Birkhill-shale group. The deepest beds visible are those of the upper portion of the *D.-vesiculosus* band, hard and flaglike, and yielding *Diplograptus vesiculosus* (Nich.), *Monograptus tenuis* (Portlock), &c. These are followed by the variegated beds of the *M.-gregarius* zone, which, much faulted, and succeeded irregularly above by the grey group of the Upper Birkhill Shales, with *Monograptus spinigerus*, *M. tenuis*, &c., occupy the remainder of the exposure, and pass below the greywackes to the south at an angle of about 60°.

ii. *Eldinhope Burn* (fig. 17).—On the opposite side of the Yarrow a small section is visible in the burn of Eldinhope, about 200 yards above the small cottage. On both sides of the exposure the greywackes dip from off the Moffat beds at an angle of about 45°. Of

the Moffat beds themselves only the highest beds are visible. To the south a group of grey shales, folded and broken, crops out immediately below the greywackes, with the lithological characters of the *R.-maximus* band, and furnishing in excellent preservation its peculiar fossils, *Rastrites maximus*, *Monograptus runcinatus*, &c.

Fig. 17.—*Section in Eldinhope Burn.*

D. Flagstones, shales, and greywackes.
Cb. Grey shales with black and white seams, containing *Rastrites maximus* &c.
(2) Zone of *Monograptus spinigerus*. *f.* Fault.

All the central beds are hidden from sight by masses of boulder-clay and alluvium ; but on the north side of the arch a boss of black shale emerges, and affords one of the finest sections of the *M.-spinigerus* zone in the south of Scotland. About 20 feet of its beds are exposed, and show the peculiar cytheroid concretions, the Annelide-trails, the grey ashy seams, the reticulated laminæ, &c. we have learnt to look for in the zone, and afford a host of indifferently preserved examples of its concomitant fossils, *M. spinigerus* (Nich.), *M. tenuis*, &c.

To the north these beds pass under a shattered group of grey and black bands, with white-clay seams, which plunge below a fine cliff of flaggy greywackes.

Sundhope.—Some of the most fossiliferous beds of the *M.-spinigerus* zone are exposed on a small cliff on the side of the Yarrow, opposite the farm of Sundhope. Fossils are abundant, and, as is almost invariably the case with this zone, in a state of admirable preservation.

The flaggy greywackes are visible on both sides of the exposure ; but the intermediate beds are not exhibited.

(c) *Black Band of Ettrick and Glenkiln.*

i. *Ettrick River.*—The black-shale bands traced by us from the neighbourhood of St. Mary's Loch into the basin of the Ettrick are continued to the south-east for a few miles beyond the watershed ; but ultimately they subside, one by one, below the unbroken mass of greywacke in that direction. To this rule, however, there is one notable exception. The southern, or Berrybush, band, after disappearing for a short time near Cossar Hill, again emerges, and, sweeping in a gently curved line to the head of the valley of the Ettrick, is prolonged in numerous disconnected exposures of black shales as far as Glenkiln, near Dumfries. It demands especial notice here, as it not only affords several sections of the strata of

the lowest division of the Moffat Series, but the determination of its relation to the so-called "axial" or "Ardwell" beds, which bound it on the south, has a most important bearing upon the general Silurian geology of the south of Scotland.

At Shorthope, which may be regarded as marking the easterly commencement of the band, only Birkhill Shales are visible. These are thrown into several parallel undulations. As usual, the most conspicuous beds are the flag-like shales of the *D.-vesiculosus* and *M.-gregarius* bands of the lower group. They are greatly indurated, and yield only occasional examples of *Diplograptus vesiculosus* (Nich.), *Climacograptus rectangularis* (M'Coy), *Monograptus tenuis* (Portl.), &c. The grey and black shales of the upper group have undergone even a larger amount of disturbance, but are easily recognized by their peculiar mineralogical characters and their relation to the surrounding greywackes.

At Brockhope the band widens greatly, and exposes the underlying Hartfell Shales, the "Barren Mudstone" occupying its natural position in the centre of the band.

Some of the deeper beds of the Hartfell Shales are visible at Phawhope, where for the first time we are presented with an exposure showing the Grey group passing below the greywackes to the north. To the south the same beds, with their characteristic white-clay bands and peculiar fossils, *Monograptus Halli* (Barr.), *M. spinigerus* (Nich.), lie distinctly between the greywackes and the black division of the Birkhill series in several localities.

Beyond Phawhope the band crosses the watershed into the head of Selcoth Burn, and forms one of the three bands of Craigmichan Scaurs, where its characters and relationships have been already described.

Everywhere along this extended line the axis of the anticlinal is so greatly inverted that the Upper Birkhill Shales seem to repose at a very small angle upon the greywackes to the south.

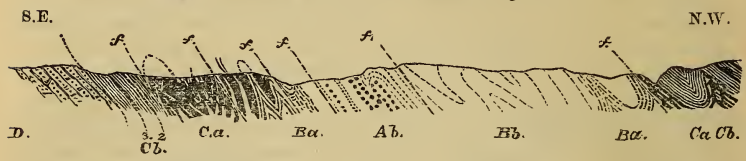
Two other anticlinals of Craigmichan are also partially visible in the Ettrick valley. The central arch crosses the river above Phawhope, but soon disappears.

ii. *Entertrona.*—The southern arch is best exhibited in the small burn called Entertrona, where beds of the Glenkiln division are abruptly collocated with the greywackes to the north, and yield *Leptograptus*, sp., *Didymograptus superstes* (Lapw.), *Dicellograptus divaricatus* (Hall), *Climacograptus cælatus* (Lapw.), *Diplograptus* (?) *bimucronatus* (Nich.), *Cœnograptus gracilis*. They are faulted against the upper or grey group of the Birkhill Shales, which show the black, white, and grey lines with which we are already so familiar. The fossils present include, among others, *Rastrites maximus* (Carr.), *Rastrites hybridus* (Lapw.) *Retiolites perlatus* (Nich.), *Monograptus runcinatus* (Lapw.). These fossiliferous strata dip steadily to the southward at a small angle, passing upwards into the barren flagstones and greywackes of Ettrick Pen.

iii. *Belcraig Burn* (Pl. XIII. Plan H).—Several exposures of the dark shales of this band occur in the heights to the south-west of

Craigmichan Scaurs, but no intelligible transverse sections are visible till we reach the lower portion of Belcraig Burn, a small stream falling into the Annan about 4 miles from the town of Moffat (fig. 18).

Fig. 18.—*General Section, Belcraig Burn.*



D. Flaggy greywackes with shaly partings.
Cb. Grey flaggy shales with lines of white clay and seams of black fossiliferous shale.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Black flaggy shales with seams of coloured mudstone. *Diplograptus vesiculosus* &c.
Bb. Mass of flaggy mudstones pale, non-fossiliferous.
Ba. Shattered slaty shales, with *Leptograptus flaccidus*, &c.
Ab. Pale shales and flaggy beds, with band of thin black pyritous shales yielding *Cœnograptus gracilis, Dicellograptus sextans*, &c. *fff.* Faults.

Here the black and grey shales and mudstones of the Moffat Series are seen partly in the main stream, partly in the course of a small tributary which enters from the south. The chief axis of the master anticlinal into which the strata of the band are thrown is, as usual, greatly inverted, all the beds without exception dipping at a steep angle to the west-north-west.

The south-eastern side of the arch shows an ascending succession through the Birkhill Shales into the overlying greywackes: on the opposite side the latter are buried beneath the coarse conglomerate which here forms the basal bed of the Permians of Dumfries.

The Glenkiln Shales occupy the centre of the anticlinal. In the main stream they form a rude arch, and the only beds exposed are the black flaggy highly siliceous shales seen at Dobb's Linn. They afford *Didymograptus superstes* (Lapw.), *Dicellograptus sextans*, and a few other forms. In the side stream, the group is represented by the soft white and yellow beds of Craigmichan—barren, concretionary, or with cuboidal fracture—together with two soft black beds, much crushed, but affording numerous examples of such characteristic forms as *Didymograptus superstes* (Lapw.), *Cœnograptus gracilis* (Hall), *Dicellograptus sextans*, &c. &c.

To the north-west these Glenkiln beds are faulted against a mass of the "Barren mudstone" of Upper Hartfell age, which is admirably exposed in both streams. As no convolutions are visible, its thickness is apparently greatly in excess of that of the same zone in any other known locality. At the junction of the streams, the mudstone is underlain by a fragment of the *Pleurograptus* zone of the Lower Hartfell, with *Pleurograptus linearis* (Carr.), *Leptograptus flaccidus* (Hall), &c. The same zone recurs on the opposite side of the Glenkiln Shales, and affords similar fossils.

The Hartfell beds are faulted in their turn against the Birkhill

Shales, and of these there is here exposed the most complete section known to me as existing on the southern side of this band; and the proof it affords that the Ardwell beds stand in the same relationship to the Moffat Series as all the greywackes to the northward is indubitable and overwhelming.

Two small arches at the base of the group bring up the soft shivery shales of the *D.-acuminatus* band, with their characteristic fossils. These are followed by a great thickness of hard flaggy beds, showing in their upper portions the variegated mudstones of the *M.-gregarius* zone, and yielding in abundance *Diplograptus vesiculosus*, *Climacograptus rectangularis* (M'Coy), and, higher up, *Monograptus gregarius* (Lapw.), *Rastrites peregrinus* (Barr.), &c.

The lowest zones of the Upper Birkhill Shales are much broken; but the majority of their characteristic fossils may be collected.

The highest or *R.-maximus* division can be identified at a glance; the grey shales with black bands, the yellow and white clay seams, &c. are clearly shown and perfectly unaltered. The commonest fossils are *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.), *M. Hisingeri* (Carr.), and *M. runcinatus*, Lapw.

These strata are separated from the greywackes to the south by a few feet of shales and flaggy beds as in other localities, all the strata being inverted, and dipping to the north-west at an angle of about 45°.

On the opposite margin of the band, a few feet of the lowest portion of the grey group are visible in a small projection at the junction of the two streams. They swarm with beautifully preserved examples of *Diplograptus cometa* (Gein.), *Monograptus leptotheca* (Lapw.), &c. To the south-east these beds are faulted against the Hartfell Shales; to the north-west the remainder of the succession is obscured by turf and heather.

Duffkinnel.—Beyond Belcraig the Silurian rocks are buried beneath the coarse Permian deposits of the vale of the Annan. They again emerge in rolling ground near Raehills, and numerous indifferent sections are apparent in the banks of the various mountain-streams. The most important is that of Duffkinnel, where dislocated and altered Birkhill Shales swarm with beautifully preserved Graptolites.

iv. *Glenkiln Burn* (Pl. XIII. Plans F, G).—Continuing our course in the same general direction to the south-west, we finally reach the notable sections of Glenkiln Burn. The dark shales are here exposed in two distinct sections, which are divided from each other by a band of greywackes a quarter of a mile in width.

Lower Exposure (fig. 19).—The first of these sections occurs at the spot called Black Linn. With the exception of one small group of strata, all the beds exhibited belong to the lowest division of the Moffat Series. Of the beds of this division, indeed, this may be regarded as the typical exposure. They are here clearly separated from those of the succeeding divisions, and at the same time swarm abundantly with their characteristic fossils. Hence their special title of the Glenkiln Shales.

The physical arrangement of the Moffat rocks of this locality will be evident on a study of the accompanying plan (F) and sections. A small cliff at the southern extremity of the section exhibits a synclinal of Lower Hartfell Shale, broken by faults, but with its strata little altered. The central portions of the trough are formed of the hard flag-like black shales of the *Dicranograptus* zone, and afford its characteristic fossils, *Dicranograptus ramosus* (Hall), *D. Clingani* (Carr.). To the south beds of grey and black shale, with numerous flinty ribs, are exposed in the bed of the stream, clearly passing underneath the foregoing zone, and yielding in relief *Climacograptus Scharenbergi* (Lapw.), *C. Wilsoni*, &c., the commonest fossils of the lowest or *Climacograptus-Wilsoni* zone of the Hartfell Shales.

Fig. 19.—*Glenkiln Burn.* (Lower Section, *Black Linn.*)

*Ba*². Flaggy black shales with *Dicranograptus ramosus, Climacograptus caudatus*, &c.
*Ba*¹. Black slaty shales with ribs of grey rock. *Climacograptus Wilsoni*, &c.
A. Pale mudstones and dark shales with seams and beds of hard flagstone, much disturbed.
Aa. Pale shivery mudstones, contorted, non-fossiliferous.
Ab. Black shales with a few seams of grey flag. *Cœnograptus gracilis, Thamnograptus, Didymograptus*, &c. *fff*. Faults.

The northern side of the synclinal is inverted, and these beds again emerge in that attitude from below the *D.-Clingani* zone in the reverse order.

They are in contact with a thick group of shivery shales and mudstones, dull grey, brown, and black, with intercalated beds and bands of hard siliceous rock, from an inch to a foot in thickness. These beds are greatly faulted and broken, and are wholly destitute of fossils throughout. At the foot of the small stream entering from the northward they are followed abruptly by a thickness of 20 feet of black flaggy shales, crowded with fossils, principally *Cœnograptus gracilis* (Hall), *Cœnograptus surcularis* (Hall), *Thamnograptus typus* (Hall). These fossiliferous beds are beautifully exposed at the foot of the tributary stream, where they are seen to contain some of the peculiar grey ribs already noticed.

To the north-west they are succeeded by a great thickness of soft grey, white, or brown shivery mudstones, barren of fossils, dipping steadily up the little burn for nearly a hundred yards.

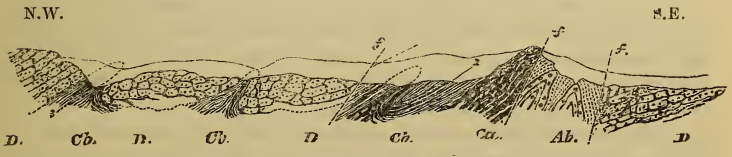
On the south bank of the main stream the peculiar dark shales and mudstones, with intercalated ribs of hard grey flagstone, fill up the whole section between the fossiliferous zone above mentioned and two contiguous bands of hard flaggy black shales, which are exposed

in the sloping cliff above a deep shaft or bore-hole, unfenced and obscured by vegetation, marking the spot where some enterprising speculator, misled by the black colour of these rocks, has foolishly excavated them in search of coal. These shales yield an abundance of badly preserved Graptolites. The majority are identical with those of the black flags already described; but there occur in addition *Didymograptus superstes* (Lapw.), *Dicellograptus sextans* (Hall), *Dicranograptus formosus* (Hopk.), *Didymograptus serratulus* (Hall), &c.

To the northward the rocks exhibited at this locality must be faulted against the greywackes of the neighbourhood, which occupy the bed and banks of the stream for the succeeding quarter of a mile, beyond which we reach a second section of the rocks of the Moffat Series.

Upper Exposure (fig. 20).—The greywackes terminate, as abruptly as they commenced, against a mass of the Glenkiln Shales, which here form an irregular anticlinal, and yield numerous well-preserved fossils, identical with those occurring in the black flags at the junction of the two streams of our former exposure.

Fig. 20.—*Glenkiln Burn.* (Upper Section.)



D. Flagstones and greywackes, with partings of shale, grey and purple.
Cb. Grey and purple shales, with seams of black shale.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Black flaggy shales, with partings of variegated mudstone and clay.
Ab. Black shales, grey and white mudstones, &c., with *Dicranograptus ziczac*, *Thamnograptus typus*, &c. *fff.* Faults.

They are faulted in their turn against a highly contorted section of the Birkhill Shales. The lower beds of the latter are well exhibited in a naked cliff on the east side of the stream overlying the Glenkiln Shales, too shattered to yield more than a few of their characteristic fossils, but easily identified by their peculiar variegated seams of mudstone and clay. They are prolonged in the cliffs of the west bank, where they yield an abundance of well-preserved Graptolites. Here the *M.-spinigerus* zone and its associated beds are conspicuous, and furnish, as usual, exquisitely preserved examples of *Monograptus spinigerus* (Nich.) and *M. Hisingeri* (Carr.). The *R.-maximus* band is cut out in the bed of the stream at this point, but its fossils can be collected in the beds shown in the cast cliff beyond. It rises again to the surface at the angle of the burn among the greywackes about 200 yards further to the northward, where it yields numerous examples of *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.), &c.

§ III. *Description of the Sections of the Moffat Series to the North of the Moffat-Yarrow Valley.*

In the great sheet of thick-bedded arenaceous strata out of which is carved the broad mountain ridge of Whitecombe and Hartfell, with its bounding valleys of Annandale and Meggatdale, a large number of exposures of the dark shales and mudstones of the Moffat Series are apparent. Judging from their geographical arrangement, it is tolerably evident that, as usual, they are disposed in several subparallel lines or bands, each of which will probably be found to mark the position of one of the more important anticlinals of the rocks of the region. In none of these bands have we the same clear evidence of continuity among the black beds as that furnished by the ground to the south of the Moffat valley. At the same time there are few individual sections so complete or satisfactory as the majority of those already described. Fortunately, however, our thorough acquaintance with the lithology and fossils of the various zones enables us to identify them almost at a glance; and, as their original sequence has been conclusively established, we can now afford to dispense with a large proportion of the confirmatory evidence so necessary in our preliminary investigations.

It will be seen from the general map of the district (Pl. XI.) that seven bands of dark shale are present to the north of the Moffat valley, viz. those of (1) Dobb's Linn, (2) Polmoody, (3) Frenchland, (4) Carrifran and Garple, (5) Auchencat Burn, (6) Hartfell Spa, and (7) Headshaw Linn.

It will be needless to describe each of these with the same care as that we have bestowed on the typical bands to the south of the Moffat-Yarrow valley. Indeed, from the very doubtful continuity at the surface of the strata of which these bands are composed, the same method of treatment is obviously inapplicable. In this case it will be more satisfactory if we describe in brief the chief exhibitions of the dark shales, and give such a general account of the remainder as may suffice to make it clear that, in the northern half of the Moffat district, the zones and fossils of the Moffat Series are identical with those in our former sections, and that they stand in precisely similar stratigraphical relations to the neighbouring greywackes.

For this purpose we may conveniently regard the present region as being composed of the three areas drained respectively by (1) the Annan and its chief tributary, the Evan, (2) the water of Meggat, and (3) the Moffat water.

The best sections are found in the first-named area, those least satisfactory (with the notable exception of Dobb's Linn, already described) in the area drained by the Moffat water.

(a) *Basin of the Upper Annan.*

i. *Frenchland Burn* (Pl. XIII. Plan E).—One of the most intelligible exposures of the Birkhill Shales to the north of the Moffat valley

is visible along the lower course of the small stream called Frenchland Burn. The section at this locality possesses an additional interest for geologists from the circumstance that it was the only section of the Moffat Series examined personally by Sir Roderick Murchison. He described the general appearances of the pyritous mudstones and the surrounding greywackes with some minuteness, noticing especially their greatly disturbed condition, but carefully refrained from hazarding any opinion as to their interrelationships. (Q. J. G. S. vol. vii. p. 161.) With our present experience we can now unravel the succession with comparative ease and certainty.

From the point at which the black shales emerge from below the Permian conglomerates of the vale of the Annan to that where they finally subside beneath the flagstones and greywackes of the Gala group is about three fourths of a mile. Midway between these points, however, the greywackes occupy the stream-course for a distance of about one fourth of a mile, so that there are actually two separate exposures of black shales. The general direction of the stream is almost coincident with the strike of the rocks, and consequently only a very small proportion of the whole of the Moffat Series is exposed. On both sides the greywackes approach nearly to the bottom of the hollow, the black shales being confined to the bed and banks of the burn.

The two exposures show precisely the same succession, viz. all the Birkhill Shales above the zone of *Diplograptus acuminatus*; but the lower exposure affords the most satisfactory sections of the beds, while the upper yields the more numerous fossils.

In the lower exposure the beds, which are highly contorted, show the usual irregular but prevailing dip to the N.N.W. Their arrangement may be gathered from the accompanying plan. Some hard black flags near the centre of the exposure yield *Diplograptus vesiculosus* and its associates, and pass into softer and more pyritous strata, which in their turn are in contact with the grey and black shales of the Upper Birkhill group. To the south the latter are inverted, but are seen to pass gradually into the overlying greywackes. To the north, where a small waterfall marks the summit of the formation, a small fault occurs, and the dark seams here are highly fossiliferous, and yield beautifully preserved specimens of such characteristic forms as *Monograptus Becki* (Barr.), *M. Halli* (Barr.), *M. Hisingeri* (Carr.), and *Diplograptus folium* (His.).

The higher exposure adds nothing to our physical evidence, but furnishes us with an abundance of Birkhill fossils. To the south its beds are faulted against the greywackes; to the north the point of junction is not visible. They dip almost invariably to the N.N.W., but are, in truth, arranged in several inosculating anticlinal forms. In all, the predominating strata are those of the Lower Birkhill Shales; the peculiar pyritous beds of the *M.-gregarius* zone are especially conspicuous, swarming with their characteristic Graptolites. The grey-shale group is also visible for some distance; but only a few of its fossils have been obtained.

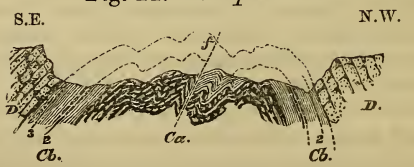
ii. *Garple Spa* (Pl. XIII. Plan J).—To the west of the valley of the

Annan the Moffat Shales are exposed in a deep gorge lying along the course of the Garple Water, a small tributary of the Evan. Deep, narrow, and overhung with a thick growth of trees and underwood, the picturesque little glen is a favourite resort of tourists and pleasure-seekers. The burn toils between perpendicular cliffs of the hard grits and greywackes of the Gala group, more than ordinarily coarse and massive, and weathering of a dull purple colour. About half a mile from the mouth of the gorge the grits retreat from the edge of the stream, which here flows through a narrow haugh of alluvium, and lays bare in its course several capital exposures of the highest division of the underlying Moffat Series.

The most ancient strata visible at this spot belong to the *D.-vesiculosus* zone of the inferior division of the Birkhill Shales. They form a low arch, the axis of which crosses the course of the stream at a very oblique angle. This arch is conspicuously exhibited at the point N. of the plan, in the north bank of the stream. Two small exposures of the overlying beds are apparent a little below. In that on the southern margin of the burn a partially inverted section shows the junction of the Lower and Upper Birkhill Shales. The latter are the grey flaggy shales and dark seams of the lower beds of the *M.-spinigerus* zone, with white-clay bands and calcareo-ferruginous nodules. Fossils are abundant and in good preservation, principally *Monograptus Hisingeri* (Carr.), *M. Clingani* (Carr.). A small section on the opposite side of the stream exposes grey and black shales somewhat higher in the vertical series.

In the prolongation of the axis of the main anticlinal to the south-west, a highly fossiliferous exposure of the *M.-gregarius* zone is visible in the south bank of the stream. The strata are greatly disturbed; but their soft, highly pyritous nature, and the numerous intercalated seams of variegated mudstone, enable us to identify them at first glance with the corresponding beds of Dobb's Linn. They yield excellent specimens of *Rastrites peregrinus* (Barr.), *Monograptus gregarius*, *M. leptotheca* (Lapw.), *M. cyphus* (Lapw.), *M. lobiferus* (M'Coy), *M. intermedius* (Carr.), *Diplograptus palmeus* (Barr.), *D. tamariscus* (Nich.).

Fig. 21.—*Garple Linn.*



D. Thick-bedded purple grits and flags.
Cb. Purple and grey shales with black seams.
3. *Monograptus Halli.* 2. *M. spinigerus.*
Ca. Contorted black flaggy shales with partings of variegated mudstone. *M. triangulatus*, &c. *f.* Fault.

About a hundred yards above this point the stream suddenly

turns at right angles to its former direction and lays bare a complete transverse section of the Moffat beds of the locality (fig. 21). In spite of the convoluted state of many of the beds, the arrangement of the black shales is easily interpreted, and is demonstrative of the infraposition of the Birkhill beds to the neighbouring greywackes. To the north the latter form a steep cliff, beneath which the purple shales of the *R.-maximus* zone, here barren of fossils, plunge at a very steep angle. Below these the grey and black shales of the *M.-spinigerus* zone are recognizable. A few of its black bands are here very prolific, swarming with multitudes of *Monograptus spinigerus* (Nich.), *M. Hisingeri* (Carr.), *Retiolites perlatus* (Nich.), *Diplograptus Hughesi* (Nich.), &c.

Similar beds, greatly disturbed, form the floor of the stream for some distance. The lowest grey band is much hardened, and where it finally disappears gives rise to a small waterfall, beyond which the underlying *M.-gregarius* zone comes to the surface. Its beds form the north bank of the stream above the cascade. It is highly interesting to note the presence in its central division of the thick seam of ironstone nodules so conspicuous at Dobb's Linn. Here also the soft pyritous mudstones which are immediately in contact with it swarm with *Monograptus triangulatus* (Harkn.), *Diplograptus modestus* (Lapw.).

The overlying *M.-spinigerus* zone of the Upper Birkhill Shales is much more disturbed than it is on the opposite leg of the anticlinal, but it may be identified both by mineralogical characters and by fossils. The beds of the succeeding purple-shale zone, on the other hand, are admirably exhibited. They dip steadily below the thick-bedded greywackes of the south cliff at a small angle, and yield a few characteristic fossils, preserved with their full relief.

iii. *Rittonside.*—Higher up the valley of the Evan, viz. at Middlegill, Rittonside, and Headshaw, there are additional exposures of the dark shales. The first of these is almost valueless for our present purpose; but at Rittonside a fairly intelligible section is afforded by the walls of the railway-cutting above the small cottage. Here, as at Belcraig, the Graptolitiferous beds are traversed by an enormous dyke of greenstone, and are greatly shattered. In the centre of the section the hard black flags of the *D.-vesiculosus* zone are apparent, and furnish, among others, *Diplograptus vesiculosus* (Nich.), *Climacograptus scalaris* (His.). On both sides they are followed by faulted wedges of the pyritous and variegated shales of the succeeding *M.-gregarius* zone, replete with *Monograptus gregarius* (Lapw.), *Diplograptus tamariscus* (Nich.), and their usual associates. Between these and the hard greywackes of the remainder of the cutting are some fragmentary patches of purple and grey flaggy beds, which represent the highest or "grey" division of the Birkhill shales.

iv. *Headshaw Linn.*—The dark beds are here exposed in the normal score or gorge dug out by the waterfall marking the junction of the Gala and Moffat formations. The majority of the beds are intensely metamorphosed, being changed into a soft flaky mass of a deep

purple colour. A small boss of unaltered strata at the entrance to the gully shows the soft pyritous beds of the *M.-gregarius* zone, with their lines of variegated mudstone and yielding good examples of *Monograptus cyphus*, *M. gregarius* (Lapw.), *Diplograptus tamariscus* (Nich.), *D. folium* (His.).

To the north the flagstones and greywackes of the country are underlain by a band of 4 or 5 feet of purple shales, which reposes at once upon the *M.-gregarius* zone. On the south side of the section a much greater thickness (about 30 feet) of these purple shales occupies a similar position.

v. *Hartfell Spa* (Pl. XIII. Plan K).—Three miles to the eastward of Rittonside we reach the magnificent exposure of Hartfell Spa. At this locality the Moffat Shales occur in the broad mound called Arthur's Seat (2398 feet), which forms the south-western buttress of the mountain of Hartfell (2600 feet). In the flank of this mountain an enormous gash has been eroded, about a quarter of a mile in length and from two to three hundred feet in depth, which forms a striking feature in the view of the ridge for many miles to the south-east. The name of the spot is derived from a mineral spring which rises among the dark shales in the centre of the exposure, and which has long been celebrated for the strength and efficacy of its waters.

The black shales of the Hartfell band here rise to the surface in an elongated ellipse, or narrow lenticle, about three miles in length. It is about a quarter of a mile in diameter at its centre, thinning away almost to a point at its opposite extremities. It is formed by a single master anticlinal of the Moffat Series, composed of numerous subordinate and very irregular arches. Nowhere to the north of the Moffat valley are the dark shales so greatly folded and shattered as in this locality; but, on the other hand, nowhere are the fossils so prevalent throughout the beds; so that the deficiencies in the stratigraphical evidence of the sequence of the strata are amply compensated by the extra facts derived from palæontological considerations.

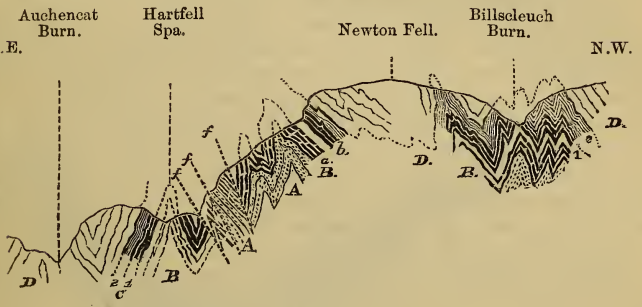
Birkhill Shales.

As in all our former sections, the highest beds rise from below the greywackes at the extremities and along the inner margin of the ellipsoid. At its south-westerly extremity the stream has cut the narrow gorge known as Frizzle's Linn, generally along the line of junction of the grits and mudstones. To the north of the stream at this point the grits are visibly in conformable contact with a thin group of drab, grey, and black shivery mudstones, similar to those of Rittonside and Headshaw Linn, but in a perpendicular or even slightly reversed attitude. Fossils are numerous, but indifferently preserved, viz. *Monograptus gregarius*, *M. tenuis* (Portlock), and *Dawsonia campanulata* (Nich.).

The stream occupies a similar position with respect to the underlying rocks as far as the foot of the Spa Score, and affords at least two additional sections of the higher zones of the Moffat Shales.

The first of these exposures occurs at the Old Copper-mine; here a horizontal shaft runs from the level of the stream into the flank of the steep ridge to the southward, and exhibits a small section of shattered Birkhill Shales, faulted against thick-bedded grits, off which they dip, apparently to the northward, at steep angles. The black shales are much contorted and stained with the green carbonate of copper, the presence of which originally led to mining-operations at the spot. The fossils obtainable are those of the *M.-gregarius* zone, viz. *Monograptus gregarius* (Lapw.), *M. tenuis*, *Diplograptus tamariscus* (Nich.), and a few others.

Fig. 22.—*General Section through the Hartfell exposure.*



D. Greywackes and flagstones.
B. Birkhill shales: 2. Upper; 1. Lower.
B. Hartfell shales: *b.* Upper; *a.* Lower.
A. Glenkiln shales. *ff.* Faults.

The second exposure is met with about 200 yards higher up the stream. The black shales, which are here pierced by a small felstone dyke, show the nodules and variegated mudstones of the higher *M.-gregarius* zone, and yield in some abundance *Monograptus gregarius* (Lapw.), *M. fimbriatus* (Nich.), *M. lobiferus* (M'Coy), *Diplograptus vesiculosus* (Nich.).

In the Spa Score itself, immediately above the mineral spring, the greywackes cap the south cliff for a long distance, and are either in a perpendicular attitude or dip steeply to the south-east. They are immediately underlain by a few feet of shattered shale and mudstone, much wrinkled, and weathering of a pale orange colour, but exhibiting several conspicuous seams of white-clay shale. These form the summit of a great mass of highly contorted black shales and flags, pierced by dykes of felstone. In spite of their greatly shattered and, indeed, more or less altered character, we easily recognize the zone of *Monograptus gregarius*, with its characteristic variegated mudstone seams; and two long parallel rows of hard black flags projecting above the general face of the cliff from end to end are immediately assigned to the *D.-vesiculosus* band. The strata are so convulsed that it would be impossible to lay down any line of demar-

cation between the various zones, and the included fossils are consequently placed here in a single list.

Monograptus gregarius (*Lapw.*).
—— leptotheca (*Lapw.*).
—— cyphus (*Lapw.*).
—— tenuis (*Portl.*).
—— communis (*Lapw.*).
—— attenuatus (*Hopk.*).
Diplograptus vesiculosus (*Nich.*).
—— folium (*His.*).
—— acuminatus (*Nich.*).
—— modestus (*Lapw.*).
—— tamariscus (*Nich.*).
Climacograptus normalis (*Lapw.*).

It will be apparent that here, as everywhere to the north of the Garple Band, none of the Upper Birkhill fossils are present.

Along the north-western margin of the ellipsoid the same Birkhill Shales clearly constitute its marginal beds, passing below the succeeding flagstones and greywackes.

In Billscleuch there is an exposure of these strata about half a mile in length (fig. 22). They form two distinct subordinate anticlinals, separated from each other by a narrow patch of greywacke. The shales are perhaps less shattered than those in the Spa Score, but are much more intensely altered. The lowest strata seen are certain pale shales coming into the place of the Barren Mudstone of the sections to the south of the Moffat valley. Certain hard flaggy beds which succeed probably represent the zones of *D. vesiculosus* and *M. gregarius*. One band only is fossiliferous; it contains *Monograptus cyphus* (Lapw.) and *Diplograptus tamariscus* (Nich.).

The grey flagstones and shales of the Upper Birkhill Shales certainly occupy much of the section between this unaltered band and the greywackes. Beyond the fact that many of the highly altered pale or cream-coloured beds show occasional seams of milk-white mudstone no reliable evidence of their presence is obtainable.

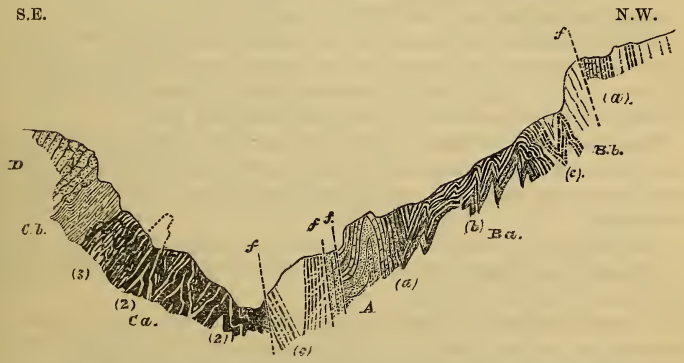
In Potburn, half a mile to the north-eastward, a similar group of beds is visible. The strata are here less altered, and the majority of the Lower Birkhill Graptolites are present.

The shivery mudstone that everywhere underlies the greywackes forms the extreme north-easterly point of the ellipsoid at the head of Blackshope Burn, the surrounding cliffs showing the massive gritstone of the Gala group. In the very centre of the ellipsoid, midway between the Spa Score and that of Billscleuch, a patch of greywacke occurs on the ridge. Its northern margin is not exposed, but its southern limit can be made out for about 200 yards above the cliffs of the gorge. The grits dip to the southward at an angle of about 40°; and there comes out from below them a band of grey shales greatly indurated, representing the upper portion of the Birkhill Shales. Along the south-western margin of this patch the pyritous and flaggy black shales of the zones of *M. gregarius* and *D. vesiculosus* are visible at the head of some small trough-like scores, and yield indifferently preserved Graptolites of the characteristic species *Monograptus gregarius* (Lapw.), *M. tenuis* (Portl.), *Diplograptus tamariscus* (Nich.), *D. vesiculosus* (Nich.).

Hartfell Shales.

Nowhere throughout the whole of the Moffat district or, indeed, in any single locality in the south of Scotland, is there to be seen so magnificent an exposure of the black flaggy beds of the middle division of the Moffat Series as is exhibited in the northern cliffs in the score at Hartfell Spa (fig. 23). It is for this reason that I have grouped the whole of the beds of this division under the general title of the Hartfell Shale, though the higher or Barren-Mudstone subdivision is far less conspicuous than in the sections to the south of the Moffat valley, and the terminal or *D.-anceps* band can nowhere be recognized.

Fig. 23.—*Section through the upper end of Hartfell Score.*



D. Grits and flagstones. *Cb.* Grey shales with white seams, shattered.
Ca. Black flaggy shales, with (3) *Monograptus gregarius*, (2) *Diplograptus vesiculosus*, *D. acuminatus*, &c.
Bb. Pale non-fossiliferous mudstones.
Ba. Black slaty shales. (*c*) Zone of *Pleurograptus linearis*. (*b*) Zone of *Diplograptus Clingani*. (*a*) Zone of *Climacograptus Wilsoni*.
A. Pale shales with hard grey and flinty ribs, non-fossiliferous. *fff.* Faults.

Much of the ground within the glen is too complicated ever to be perfectly mapped; but the general arrangement of the rocks can be easily made out. The disposition of the more important zones is given in the accompanying plan and sections (Plan K, Pl. XIII.; sections figs. 22, 23).

Roughly speaking, the Moffat beds of the glen are arranged in five subparallel anticlinal forms.

The axis of the first fold crosses the stream-course obliquely below the mineral spring. The lowest beds brought to the surface are those of the *Dicranograptus-Clingani* zone of the Hartfell Shale. To the south the strata of this anticlinal are faulted against the greywackes of the south cliffs; to the north they pass up into the Birkhill Shales already described.

The axis of the second or main anticlinal of the glen runs parallel with the central portion of the bottom of the gorge from end to end.

As in numberless instances in the Moffat district, the line of the axis is coincident with that of a longitudinal fault, which here lets in a long, thin, and crumpled wedge of Hartfell Shales between it and the fault bounding the Birkhill beds of the southern cliffs. To the north of the faulted axis excellent sections of the Lower Hartfell Shales are seen in the northern cliffs, crowded with their characteristic fossils, but highly convoluted. The axes of all the small folds which can there be detected rise to the north-east; and two are of sufficient importance to again bring up to the surface the higher beds of the Glenkiln Shales.

A third anticlinal of some importance is shown at the north-eastern summit of the north cliff, which also exposes a few feet of the underlying Glenkiln Shales. The axes of all these anticlinals, principal and subordinate alike, are usually faulted, so that in each case only a single leg of the arch is complete at the surface.

The beds of the lowest of the Hartfell zones, that of *Climacograptus Wilsoni*, are beautifully exhibited immediately above the lines of the Glenkiln Shales; but the best localities for fossils are those at the extreme ends of the most southerly line.

The hard black flags of the zone of *Dicranograptus Clingani* occupy much of the north cliff, in the lower portion of which they may be studied with ease, or in the lateral score near the head of the gorge.

The thin slaty shales with *Pleurograptus linearis* are best exhibited near the westerly termination of the north cliff, below the fault marked upon the plan.

The pale beds of the Barren Mudstone make but a poor figure in the sections at this locality. If the orange-coloured mudstones that are exposed between the zones of *Pleurograptus* and *D. vesiculosus*, as shown at the back of the little building erected over the mineral spring, include all the beds of this subdivision, it has dwindled down to at least half the thickness it possessed at Dobb's Linn. Similar beds are visible above the *Pleurograptus* zone, towards the summit of the northern cliffs near the Glenkiln bands marked upon the plan; and small patches of the same strata are discernible in several other localities.

The mineral characters and fossils of these zones will be given in the second portion of this paper.

Glenkiln Shales.

A few feet only of the barren portion of the Glenkiln Shales are all that are exhibited at this locality. The hard flinty band at the summit forms a rude cornice or projection running along the western base of the north cliff. It is seen in the same stratigraphical position in all the remaining anticlinals, and reposes upon several feet of dark grey and pale yellow mudstones identical with those of Glenkiln and Berrybush. It is impossible to separate them by the eye from those of the Barren-mudstone division of Upper Hartfell age; many of the shales exhibited at the head of the lateral score may belong to either subdivision.

(b) *Basin of the Meggat.*

The five exposures apparent in the valley of the Meggat possibly indicate the presence of two parallel bands of the Moffat Shales. It is very doubtful whether they have any definite relation to the anticlinals already described.

Syart-Law Score.—The largest exhibition of the black shales in this area is found in a deep gash or score in the northern flank of Syart Law, opposite the farmhouse of Cramalt. The beds visible are chiefly those of the Lower Hartfell Shales. They are greatly disturbed and altered. The most fossiliferous seam belongs to the central portion of the zone of *Dicranograptus Clingani*. It affords good examples of *Lasiograptus margaritatus* (Lapw.), *Diplograptus foliaceus* (Murchison), *D. truncatus* (Lapw.), *Dicranograptus ramosus* (Hall), and *Dicellograptus Forchhammeri* (Geinitz) in several varieties.

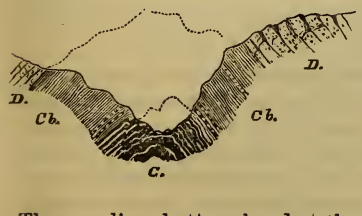
The higher portion of the zone of *Pleurograptus linearis* is also fossiliferous, yielding numerous specimens of *Diplograptus quadrimucronatus* (Hall), *Leptograptus flaccidus* (Hall), &c.

Craigierig.—About half a mile distant from the former locality, and in the prolongation of the strike of the rocks, the highest beds of the Lower Birkhill Shales are shown in the small stream at the back of the shepherd's cottage of Craigierig. Only a few feet of the fossiliferous portion of the dark shales are visible. They yield admirable examples of *Monograptus lobiferus* (M'Coy), *Diplograptus sinuatus* (Nich.), *D. tamariscus* (Nich.), and *Rastrites capillaris* (Carr.).

Similar beds are seen on the opposite side of Syart-Law Score, in the burn of Shielhope (see map, Pl. XI.).

Boar Cleuch (fig. 24).—A small but very important section of the black shales occurs in the gorge of the Boar Cleuch, a tributary of the Glengaber. The lowest beds visible in the floor of the gully are the hard black flags of the zone of *Diplograptus vesiculosus*. They are covered on both sides by the softer strata of the *D.-gregarius* zone, with their peculiar pyritous and variegated mudstones, containing scattered examples of *Monograptus gregarius* (Lapw.), *Diplograptus folium* (His.), *Dawsonia campanulata*, &c.

Fig. 24.—*Section of Boar Cleuch, Glengaber Burn.*



D. Coarse grits and flagstones.
Cb. Grey and purple flags and shales, non-fossiliferous.
Ca. Flaggy black shales with seams of coloured shales. (*Monograptus gregarius, Diplograptus vesiculosus*, &c.)

The peculiar shattery band at the summit of the zone passes below a thickness of 60 or 70 feet of hard grey flaggy shales, which gra-

duate upwards into the coarse greywackes of the country. From their position in the section there cannot be the slightest doubt that these flaggy shales are actually the upper or grey division of the Birkhill Shales of our typical localities of Dobb's Linn and the bands to the south of the Moffat-Yarrow valley. The dark fossiliferous shales and the peculiar white-clay bands have gradually vanished as we have followed the Moffat Series to the west and north to this spot, where scarcely a single trace of them remains.

The section has a further value in affording a perfect demonstration of the inferiority of the Moffat Series of the Meggatdale to the surrounding greywackes, many of which are very different in their general features from those of the southern region.

(c) *Basin of the Moffat Water.*

The typical section of the Moffat Series of Dobb's Linn, which occurs at the head of the Moffat, has been already described. The remaining sections in this area may be dismissed in a few words.

Polmoody.—A short but continuous band of black shale runs from the hamlet of Polmoody in Moffatdale towards the head of Winterhope. The only strata visible along its course are the Birkhill Shales. In the Tail Burn they yield their characteristic fossils in relief. In the scores above Polmoody their highest beds can be seen in contact on both sides with the greywackes.

Carrifran.—A second band crosses the three parallel streams of Blackshope, Carrifran, and the Midlaw Burn. In Blackshope the strata are frightfully shattered; in Carrifran the fossils of the *Dicranograptus-Clingani* zone may be collected from the dark shales in abundance. In the exposure in the mountain of Whitecombe, the grey division of the Birkhill Shales may be seen in conformable contact with the greywackes.

Bodsbeck.—A single apparition of the Birkhill Shales occurs at the spot marked on the map (Pl. XI.) upon the south side of the Moffat Water.

Shortwoodend, &c.—The highest Birkhill beds pass below the greywackes at Shortwoodend, not far from the bottom of the valley. Traces of similar fossiliferous Birkhill beds have been detected by myself at the other localities indicated.

§ IV. *Summary of Observations and Conclusions regarding the Physical Relations of the Moffat Series.*

We have now completed our examination of the sections of the Graptolitic shales and mudstones seen within the limits of the Moffat district. The details brought forward in the preceding pages or inserted upon the accompanying plans and sections, place it wholly beyond question that in all the localities mentioned the various groups of the dark shales stand in corresponding natural relations to each other, and in the same physical attitude with respect to the surrounding greywackes. In spite of the excessive disturbance, frac-

ture, and more or less alteration which these strata have undergone, the physical, mineralogical, and palæontological evidences at our command make it clear that in every intelligible section the natural sequence of the beds is identical with that in our typical section at Dobb's Linn. To the south of the Moffat valley this agreement is so exact that the sections can be compared bed for bed and fossil for fossil. To the north of the Moffat valley the dark fossiliferous seams gradually die out of the highest grey-shale group, which towards the north-west degenerates into a group of barren flagstones, undistinguishable from those which alternate with the surrounding greywackes.

So distinct and persistent, however, are the generality of the various Graptolitiferous zones in their essential characters, lithological and palæontological, that, as we have seen, they admit of immediate identification in every locality where they have not undergone excessive metamorphism. By an examination of their physical arrangement in numerous transverse sections, and by tracing them from point to point along the line of strike, we have assured ourselves of the fact that in every extended band of black shale, after the effects of the numerous faults have been allowed for, the order of the beds on both sides of the central line of the band is precisely similar. Where the main axis of the band is uninverted, the terminal zones on the opposite margins pass visibly below the surrounding greywackes. Broadly speaking, where the black-shale band is of small diameter, only the higher beds of the Birkhill Shales are apparent. As it increases in width the underlying zones emerge one by one in its centre; until finally, in the widest exposures, we meet with the deepest visible strata of the Glenkiln Shales.

We have, in addition, not only been able to satisfy ourselves of the fact that all the rocks of the district have been crumpled up in a large number of inverted folds, but we have even found it possible to trace the geographical position of several of these plications, and to measure approximately the amount of inversion. We have ascertained that this inversion is sometimes so intense that, as in the case of the Ettrick band, the overturned strata overhang the vertical to such an extent that at first glance they appear to be almost flat; at other times it is so variable in its direction that, as in Dobb's Linn, the plane of the inverted anticlinal oscillates as much as 30° on opposite sides of the perpendicular in less than 200 yards.

While therefore, on the one hand, the facts now at our command make it clear that all evidence derived from broad views of the apparent order of superposition of the strata within the present district, unless confirmed by other testimony, is not only useless but misleading, yet, on the other hand, they are amply sufficient to enable us to disentangle the complicated succession among the Moffat Shales themselves, and to establish the general identity of the surrounding and overlying greywackes.

The more important conclusions to which these facts inevitably lead us may be very briefly summed up as follows:—

1. All the black Graptolitic shales of the Moffat district are actually portions of one and the same continuous deposit.

2. They owe their repetition to a series of subparallel folds, the upper arches of which have been denuded (fig. 25).

3. They rise invariably from below the surrounding greywackes in anticlinal forms, the axes of which are usually inverted.

4. The deposit to which they belong is consequently the oldest rock-group in the Moffat district.

5. This fundamental rock-group, which is denominated by us the Moffat Series, is composed of a comparatively homogeneous assemblage of dark Graptolitic shales and pale barren mudstones.

6. Its collective thickness within the limits of the present district is about 300 feet, but its actual base is nowhere visible.

7. It falls naturally into three primary *divisions*, each of which is characterized by a special fauna, made up almost wholly of peculiar species.

8. Each of these primary divisions is again naturally subdivided into several *zones*, individually distinguished by special mineralogical and palæontological characteristics.

In the light of these results the difficulties hinted at in the early part of this paper wholly disappear.

The varying width of each of the longer shale-bands, its rapid contraction near its extremities, and its final disappearance, together with the peculiar boat-like form of the shorter exposures and their moniliform geographical arrangement, were all facts utterly inexplicable either upon the theory that the black shales occurred on

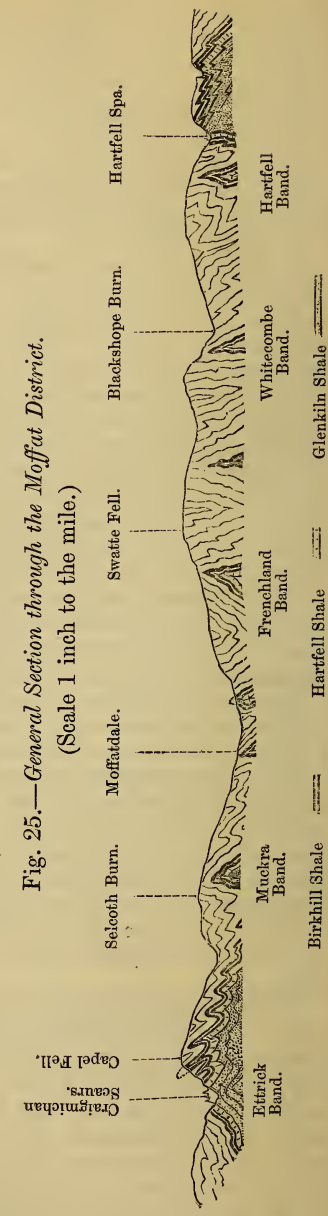


Fig. 25.—*General Section through the Moffat District.*
(Scale 1 inch to the mile.)

several distinct horizons in the great greywacke formation, or on the more popular hypothesis that they belonged to a single and persistent sheet, both underlain and overlain by arenaceous beds. They now find their common explanation in the simple circumstance that the dark shales reach the surface of the country along the chief anticlinal lines, the width of the several exposures being dependent merely upon the varying elevation of the crown of the arch.

The extraordinary diversity apparent in the various groups of species yielded by the strata of the same band in the different exposures along its course, and the peculiar localization of some of its most distinctive fossil forms, are quite as easily explained by our discovery of the rigid restriction of the Graptolitic species to definite zones. Not only do the earliest zones of each band make their appearance as a rule only in the widest exposures, but its apparent fauna in any single locality is necessarily that of the collective faunas of the special zones, which the concurrent accidents of plication, metamorphism, and denudation have there left accessible to the investigator. Lastly, we have no longer any room for astonishment at the remarkable similarity in lithological characters, the great lateral extension, persistent north-west inclination, and apparently gigantic thickness of the interminable greywackes of the Moffat district. We are now satisfied that they form in reality a single group of beds of no great vertical dimensions, the same strata being repeated again and again in rapid and partially inverted undulations.

B. Subdivisions, Lithology, and Palæontology of the Moffat Series.

§ I. *The Glenkiln Shales.*

From the foregoing description of the several sections of the Moffat Series within the limits of the present district it is evident that we are far from possessing an equal knowledge of the rocks and fossils of each of its three chief divisions. The general lithological and palæontological characteristics of the Birkhill division may be gathered from at least fifty different sections. The total number of appearances of the Hartfell Shales cannot exceed ten or twelve. Of the lowest division, or Glenkiln Shales, there are only five exposures, and in these the strata exhibited are mere fragments of the succession, cut off as a rule by slips or faults from all their original associates.

Naturally, therefore, our present knowledge of the Glenkiln division is far inferior in amount and accuracy to our knowledge of the overlying divisions. From the circumstances of the case we are unacquainted with any thing that ought properly to be regarded as the base of the division in this district. We are, however, able to determine with precision its superior limit, and at the same time to prove that in vertical extent it equals the succeeding divisions, and is characterized by a fauna correspondingly distinct.

The name of the division is derived from the burn of Glenkiln, near Dumfries, where its fossiliferous bands are most fully exhibited, and where they yield their fossils in the greatest variety and abundance. The succession is, however, there greatly interrupted by numerous faults which, running along the strike of the beds in a mass of very similar deposits, are almost impossible to detect. We are, unfortunately, unable to indicate any locality in the Moffat district where there is an absolutely uninterrupted sequence. The evidence for the order here given is partly physical, partly palæontological; it is consequently open to such slight corrections and additions as may be found to be necessary when the corresponding deposits in the Lammermuirs, Lead Hills, and Galloway are fully described.

At Hartfell (fig. 27, p. 309) the summit-bed of the Glenkiln Shales is seen to be formed of 4 feet of hard flaggy rock. This reposes upon a seam of dark shivery mudstone 8 feet in thickness, which passes in its turn into a group of pale yellow or orange-coloured shattery mudstones of indeterminable thickness.

At Craigmichan (fig. 3, p. 263) the same flaggy band is recognized in a corresponding position, supporting the main mass of the Hartfell Shales, and surmounting similar dark-gray and orange-coloured mudstones. Although only one or two insignificant faults are actually to be detected in the cliff below, yet no two sections, measured from the grey band into the heart of the Glenkiln Shales, are precisely alike. In each section we recognize a thickness of from 40 to 60 feet of barren shales of a peculiar character, apparently interposed between the highest visible black-shale bed of the Glenkiln group and the lowest black-shale band at the base of the succeeding Hartfell division (fig. 3). The evidence derived from other exposures of these strata, however, renders it almost certain that they constitute in reality the lowest visible subdivision of the Glenkiln Shales, being actually inferior in geological position to the apparently underlying black beds, which are cut out above by the faults seen near the base of the Hartfell Shales.

The majority of the beds composing the lower Glenkiln subdivision are thin-bedded shales, often finely laminated. A few show a tendency to run into concretionary forms, and occasionally weather down into irregular ellipsoids, exteriorly of a yellow or rusty orange-colour. Some are shattery mudstones, breaking up into small prismoidal splinters. Others, again, are coarser in their texture, and have a rough harsh surface; and where greatly hardened split up into thick plates with a rugged uneven face, as in many bedded traps and ashes, to which, indeed, in other respects several of these beds bear no inconsiderable resemblance. All these strata, as might, indeed, have been inferred from their mineralogical character, are totally barren of true fossils; but many are pierced in all directions by worm-burrows and the like.

The most striking feature of these barren beds is the presence among them of seams of hard flagstone, varying in thickness from a few inches to more than a foot, and occurring in definite layers

sometimes 6 feet in depth. Occasionally argillaceous, they are more frequently highly siliceous, and break under the hammer with a conchoidal fracture. Rarely, indeed, do they show any clear evidence of internal lamination, but ultimately break up under the influence of the weather into large cuboidal fragments. From their intractable character, especially when slightly metamorphosed, they form conspicuous "ribs," or projecting bands, rising above and protecting the easily weathered surfaces of the soft shales in which they are imbedded. They are rarely absent in any of the sections of the Glenkiln Shales of the Moffat area, but nowhere are they so conspicuous as in the Craigmichan exposure, where they run along the basal portions of the cliff to the north of Selcoth Burn for a distance of nearly half a mile.

In the same section, apparently below the "ribbed shale" group, we observe two distinct seams of black shales, which, with certain white or very pale-coloured mudstones and flaggy beds, occupy the central portions of the exposure. The higher black band is 6 feet in thickness, consisting of hard ringing laminæ of carbonaceous shales, some of the softer faces of which show *Diplograptus tricornis* (Carr.), *D. foliaceus* (Murch.), *D. perexcavatus* (Lapw.), *Dicellograptus divaricatus* (Hall), *Climacograptus cælatus* (Lapw.), *C. Scharenbergi* (Lapw.), an assemblage of fossils very similar in its main features to that afforded by the lowest (*Climacograptus-Wilsoni*) zone of the Hartfell division.

Few traces of this relationship, however, are exhibited by the second and southerly black band. This is similar to the foregoing in mineralogical character, but appears to be 14 or 15 feet in thickness. It yields fossils only in one small seam near its summit; these include:—

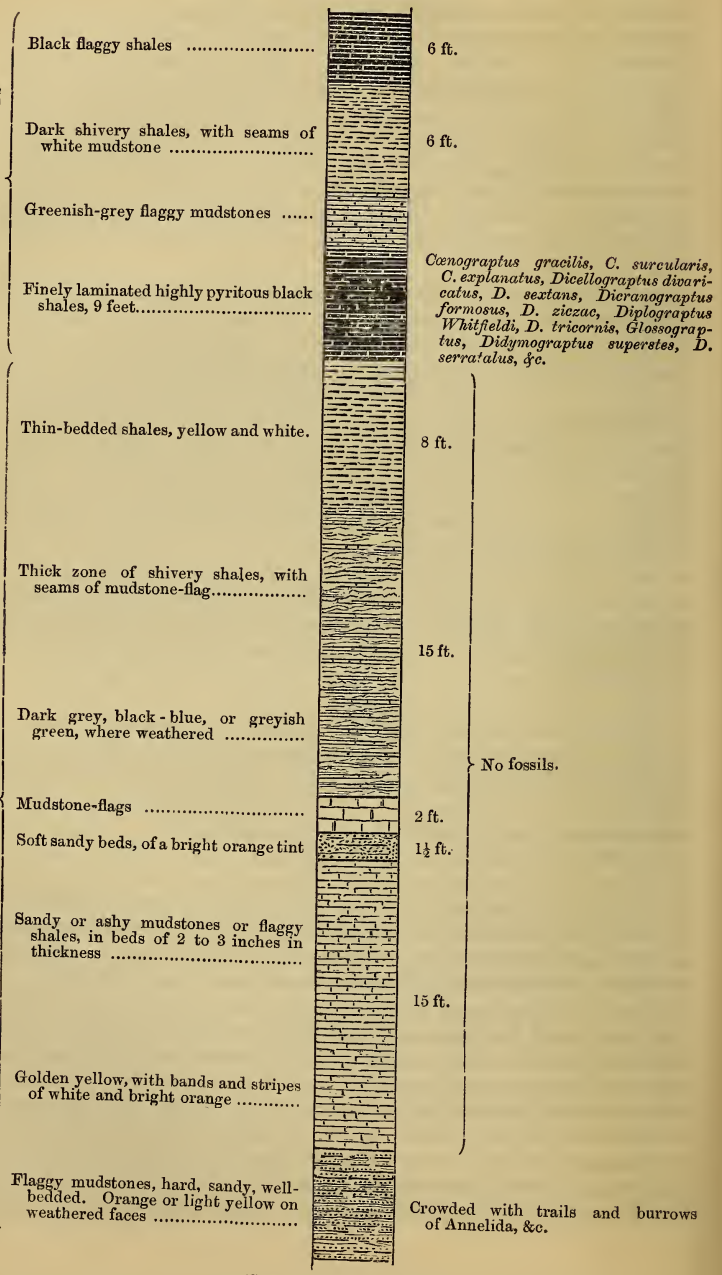
Fossils from the First Glenkiln Band of Craigmichan Scaurs.

Thamnograptus typus (*Hall*).
Dicellograptus Forchhammeri (*Gein.*).
Dicranograptus ziczac (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— angustifolius (*Hall*).
Climacograptus perexcavatus (*Lapw.*).
—— cælatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).
Glossograptus, sp.

At *Berrybush* several distinct sections show a similar thickness of concretionary and shattered mudstones and shales, with intercalated ribs of hard sandstone, in corresponding relationship to soft pale-coloured mudstones with thick seams of black shale (fig. 26).

In the eastermost of these sections, 57 feet of these barren beds are seen, here, however, distinctly dipping *below* the dark shales at an angle of 45°. They are softer and in every way less altered than in the former locality, weathering of a pale orange-colour. It is impossible to identify the dark shales; but, as will be seen from a comparison of the sections given, there can be no doubt of the equivalency of the ribbed mudstone groups. If, however, the dark shales are actually the higher beds, the section must be inverted with respect to that of Craigmichan. In the mudstones the burrows

Fig. 26.—*Vertical Section* II. Cœnograptus *Beds &c.* (*Berrybush Burn*). (Typical Section.)



(Scale, 1 inch to 10 feet.)

and trails of Annelida are exceedingly abundant upon one horizon. The dark shales are very soft, highly pyritous, and, as a rule, finely laminated and very fossiliferous. Where weathered, they contain the following fossils:—

Fossils from the Black Bands of Berrybush Burn.

Cœnograptus gracilis (*Hall*).
—— surcularis (*Hall*).
—— explanatus (*Lapw.*).
Didymograptus superstes (*Lapw.*).
—— serratulus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
—— Forchhammeri (*Gein.*).
Dicranograptus formosus (*Hopk.*).
—— ziczac (*Lapw.*).
—— Nicholsoni (*Hopk.*).
—— ramosus (*Hall*).
Diplograptus tricornis (*Carr.*).
Diplograptus foliaceus (*Murch.*).
—— angustifolius (*Hall*).
—— dentatus (*Brongn.*).
—— bimucronatus (*Nich.*).
Glossograptus Hincksi (*Hopk.*).
Clathrograptus cuneiformis (*Lapw.*).
Climacograptus bicornis (*Hall*).
—— cælatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).
Diplograptus Whitfieldi (*Hall*).

Many of these are in fragments, and few are in a good state of preservation. The most prolific band is so aluminiferous that it is almost impossible to preserve its fossils. In this respect it agrees precisely with the corresponding band of Douglas Burn, Belcraig, &c.

At Glenkiln the most intelligible section is that given in fig. 19, p. 286. The lowest beds of this age visible on the south side of the stream are three bands of black slaty shales, replete with badly preserved fossils, and associated with white or very light-coloured mudstones. The black beds yield, in the neighbourhood of the old coal-shaft, the following fossils:—

Fossils from the Black Shales of Black Linn.

Cœnograptus gracilis (*Hall*).
—— surcularis (*Hall*).
—— explanatus (*Lapw.*).
Didymograptus superstes (*Lapw.*).
—— serratulus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— Forchhammeri (*Geinitz*).
—— sextans (*Hall*).
Dicranograptus formosus (*Hopk.*).
—— ziczac (*Lapw.*).
—— ramosus (*Hall*).
—— Nicholsoni (*Hopk.*).
Diplograptus tricornis (*Carr.*).
—— foliaceus (*Murch.*).
—— augustifolius (*Hall*).
—— Whitfieldi (*Hall*).
—— bimucronatus (*Nich.*).
Glossograptus Hincksi (*Hopk.*).
Clathrograptus cuneiformis (*Lapw.*).
Climacograptus bicornis (*Hall*).
—— Scharenbergi (*Lapw.*).
—— cælatus (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).

What appear to be the same beds are seen on the opposite side of the main stream, at the foot of the small burn which enters from the north. Their fossils are obtainable in abundance in the small cliffs on the right bank of the main stream, and are, many of them, admirably preserved. All those given in the forgoing list (with the exception of the *Didymograpti*) have been here collected, and, in addition, the peculiar forms of sponges found at Dobb's Linn. To the north of these black shales a long section of very light-coloured

shattery mudstone is visible, apparently overlying them, but possibly of earlier date.

Between the two black-shale exposures lie the grey- and orange-coloured mudstones with ribs of flagstone, so conspicuous in the Craigmichan and Berrybush sections. They are, however, too much faulted and contorted to allow us to determine with certainty their precise relationship to the foregoing beds, or to those of the more recent Hartfell Shales.

The small sections of Glenkiln Shales visible at Belcraig have already been sufficiently described. That in the main stream shows only the dark shales; in the side stream many of the pale mudstones are apparent (fig. 18, p. 284).

In the main cliff at Dobb's Linn, 12 feet of the fossiliferous portion of the Glenkiln Shales are exposed. Fossils are not uncommon, but are generally in a very indifferent state of preservation.

Fossils from the Glenkiln Shales of Dobb's Linn.

Dicellograptus Forchhammeri (*Gein.*).
Didymograptus superstes (*Lapw.*).
Dicranograptus ziczac (*Lapw.*).
—— Nicholsoni (*Hopk.*).
Diplograptus foliaceus (*Murch.*).
—— tricornis (*Carr.*).
Diplograptus angustifolius (*Hall*).
—— ? bimucronatus (*Nich.*).
Climacograptus bicornis (*Hall*).
—— ——, var. peltifer (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).

Lithologically, the unfossiliferous portions of the Glenkiln Shales and the superior subgroup of barren mudstones of the overlying Hartfell division are very similar in their general features; and it occasionally happens that when the two are seen in juxtaposition it is almost impossible to distinguish them. This is not the case, however, where the intercalated flagstone ribs are present, as these are wanting from all except the very lowest Hartfell Shales. There is a corresponding resemblance in the carbonaceous beds of the two divisions, both consisting of hard black slaty shales and thin-bedded flags.

On the other hand the zoological features of the Glenkiln Shale are strikingly distinct. Its fauna is characterized by the exclusive presence of such conspicuous genera as *Cœnograptus*, *Didymograptus*, and *Thamnograptus*, none of which have hitherto been recognized in strata of later age. Even the genera common to its lower beds and those of the Hartfell Shales are represented in the two formations by species totally distinct. The most prevalent of the peculiar Glenkiln species belonging to these common genera are *Dicellograptus divaricatus* (Hall), *D. sextans* (Hall), *Dicranograptus formosus* (Hopk.), *D. ziczac* (Lapw.), *Diplograptus Whitfieldi* (Hall), *D. dentatus* (Brongn.), *Climacograptus cœlatus* (Lapw.), &c.

§ II. *The Hartfell Shales.*

The second or Hartfell division of the Moffat Series attains a thickness of about 100 feet in the typical sections of the Moffat

district. In lithological character its beds resemble those of the underlying Glenkiln division, the black shales having a corresponding plate-like or slaty structure, and the pale mudstones weathering down into similar small prismoid fragments of a deep grey or orange-yellow colour. On the other hand, the dark fossiliferous shales are more numerous, and are grouped together into a single mass, or form narrow seams of a few inches in thickness among the barren mudstones. A further distinction is shown in the absence of the peculiar ribs of hard grey siliceous flagstones so conspicuous in the underlying group.

Mineralogically the line of demarcation between the Glenkiln and Hartfell divisions is well marked, and is recognizable at a glance wherever the two groups are seen in conformable juxtaposition. The thick mass of pale flags and mudstones last described constitutes the concluding portion of the Glenkiln beds; and the base of the Hartfell division is formed by the black shales, in which fossils begin to reappear in abundance. The upper boundary-line is quite as distinct, a similar group of barren mudstones being intercalated between the fossiliferous Hartfell strata and the basal beds of the Birkhill Shales.

Palæontologically there is no actual break between the Glenkiln and Hartfell divisions. The fossils of the lower division die out one by one as we ascend the succession, and are as gradually replaced by others till the change of fauna is complete. Thus, although the two successive faunas are linked together by a large community of genera and species, yet, on the other hand, the typical beds of the two formations have scarcely a single fossil in common.

At the summit of the Hartfell Shales, on the contrary, the palæontological break is almost complete. Two Graptolites only are supposed to pass up into the overlying Birkhill formation, and even these are represented by very distinct varieties.

The fauna of the Hartfell Shales is characterized chiefly by the extraordinary predominance of the genera *Dicellograptus*, *Pleurograptus*, and *Diplograptus*. *Dicellograptus* is a survival from the Glenkiln fauna, in which, however, it plays a very insignificant part. Here, on the other hand, its individuals swarm in countless multitudes; on many horizons the surface of the shale-beds is almost hidden from sight by the complex network formed of the entangled branches of thousands of examples.

Diplograptus is common to all the divisions of the Moffat Series; but in none is it so prolific as in the Hartfell Shales, where it is fully equal to *Dicellograptus* in variety of form and abundance of individuals.

Pleurograptus, with its intimate ally, *Amphigraptus*, is strictly confined to the Hartfell division, and even within it rarely transgresses the limits of the zone to which it gives its name.

There is an extraordinary mortality among the Graptolites in this division. Not only do the peculiar types, *Pleurograptus* and *Amphigraptus*, arise, culminate, and decay within the formation itself, but *Dicellograptus*, *Dicranograptus*, *Lasiograptus*, *Glossograptus*, and

Leptograptus, survivors from the Glenkiln Shales, all become extinct before we reach its highest beds. The allied genera *Climacograptus* and *Diplograptus* are all that remain to link on the richly varied forms of the Glenkiln beds to the highly prolific but monotonous fauna of the Birkhill Shales.

(a) *Lower Hartfell.*

The Hartfell Shales fall naturally into two mineralogical subdivisions—a lower group of dark fossiliferous shales, and an upper group of pale barren mudstones.

The Lower Hartfell is essentially a homogeneous mass of black carbonaceous flags and slates, more or less fossiliferous throughout. There occur, however, numerous intercalated seams of pale-coloured argillaceous matter, sometimes hard and flinty, at other times soft and easily disintegrated, and invariably destitute of all trace of organic life. The distribution of these unfossiliferous beds allows us to recognize three successive mineralogical subdivisions, which form also the three palæontological zones of *Climacograptus Wilsoni* (Lapw.), *Dicranograptus Clingani* (Carr.), and *Pleurograptus linearis* (Carr.).

i. *Zone of* Climacograptus Wilsoni (*Lapw.*) (fig. 27).—This zone attains its most perfect development and most satisfactorily exhibits its relationship to the beds above and below it in the North Cliff at Hartfell Spa. Its basal beds run in a straight line for forty or fifty yards along the steep slope immediately above the mineral spring, distinctly overlying the soft yellow mudstones of the Glenkiln, and as clearly supporting and passing up into the main mass of the Hartfell Shales. The zone forms a long projecting cornice; its strata dipping into the face of the cliff at an angle of about 40°. They are wholly free from complication by fault or curvature, and are all in such a position as to admit of a thorough investigation.

The prominent appearance of this cornice, and its freedom from the accidents which have befallen the surrounding beds, is due to the presence of a bed of siliceous flags about 11 feet in thickness, similar in all respects to those so frequently adverted to in our description of the Glenkiln Shales, of which, indeed, it is the final band. Like them it is highly resistant of atmospheric influences, but ultimately weathers into cuboidal fragments. The bed upon which it reposes is one of the dark, greyish-black flaggy shales of the Glenkiln division, which in its turn passes downwards into a great thickness of soft yellow mudstone. These three beds are all of Glenkiln age, the Hartfell Shales commencing immediately above the siliceous band.

This last is succeeded by a grey band of about a foot in thickness, which passes upwards into $2\frac{1}{2}$ feet of soft black flaky mudstone shales, separating under the hammer into large flakes or irregular plates. These contain numerous narrow seams of shale of an open texture, with a coarse ashy feel, and spotted superficially with white or cream-coloured specks of foreign matter. The following 3 feet of strata show few of these coarser lines, and the laminæ are thinner

Fig. 27.—*Vertical Section* III. LOWER HARTFELL SHALE *&c.* (*Dobb's Linn*). (*Continued upon Section* IV. p. 315).

Thin-bedded, hard, black slaty shales.	*Climacograptus tubuliferus.*
	Leptograptus flaccidus, Retiolites filratus, Lasiograptus margaritatus, Climacograptus styloideus (var.).
Hard black flaggy shales, with seams of soft black mudstone	*Dicellograptus Forchhammeri* (vars.).
	Siphonotreta micula, Lingula, Eurypterus, ? sp.
	Horizon of *Dicellograptus caduceus.*
	Dicranograptus ramosus, Lasiograptus, sp.
	Horizon of *Climacograptus caudatus.*
Black flaggy and slaty shales; fossils rare.....	*Corynoides calycularis, Diplograptus foliaceus* (vars.), *Dicranograptus Clingani.*
Dark flaky shales, with seams of grey and white mudstone	*Corynoides, Discina, Climacograptus bicornis, C. Wilsoni, C. Scharenbergi, Diplograptus tricornis.*
	Dicranograptus Nicholsoni.
GLENKILN SHALES.	
Hard grey flags	No fossils.

Zone of *Dicranograptus Clingani.*

Zone of *Climacograptus Wilsoni.*

Zone of Climacograptus Wilsoni *&c.* (*Hartfell*).

	Discina.
Soft black shales, with seams of spotted sandy and ashy mudstone	Few fossils.
Finely laminated soft carbonaceous shales.....	*Diplograptus secalinus, Climacograptus bicornis, Diplograptus tricornis, Climacograptus Wilsoni, C. Scharenbergi, Lasiograptus Harknessi, Corynoides calycularis, Dicranograptus Nicholsoni.*
Coarse gritty beds, with seams of grey ashy shales	
Hard grey flags	
Siliceous flagstones and hard jointed shales.....	No fossils.
Soft dark shales	
Altered shales and mudstones of doubtful thickness.....	No fossils.

} GLENKILN SHALES.

and of an intense black. These, again, support two feet of somewhat similar beds, distinguished, however, by the presence of numerous thin ribs of hard grey rock. Above follows the thick mass of black flags forming the base of the *D.-Clingani* zone.

The whole of the *C.-Wilsoni* beds are totally barren of fossils, except in a few thin seams, where the laminæ are of a coarser or more open texture than usual. These swarm with Graptolites in admirable preservation. The forms collected from this zone at Hartfell Spa are given in the following list:—

Leptograptus flaccidus (*Hall*).
Dicranograptus Nicholsoni (*Hopk.*).
—— ramosus (*Hall*).
Climacograptus Wilsoni (*Lapw.*).
—— bicornis (*Hall*).
—— ——, var. tridentatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— tricornis (*Carr.*).
—— truncatus (*Lapw.*).
Glossograptus Hincksi (*Hopk.*).
Lasiograptus Harknessi (*Nich.*).
Corynoides calycularis (*Nich.*).
Discina, sp.

At Dobb's Linn the band of flinty shale at the base of the zone agrees precisely in thickness and in mineralogical character with that of Hartfell Spa. It is immediately succeeded by the $2\frac{1}{2}$ feet of platy shales. Here, however, the intercalated coarser seams have no longer the spotted appearance of those of Hartfell, but are softer and more finely laminated, and make up a much larger proportion of the beds. The remainder of the zone is formed by the deep black shales, here almost destitute of the thin ribs of harder rock, but containing more of the soft grey or cream-coloured bands (fig. 27).

The fossils are restricted as before to a few of the softer and coarser laminæ. In these they are found in a state of high relief, far exceeding in beauty of preservation those collected from any of the succeeding zones. Even the grey beds yield occasionally traces of the life of the period in the shape of burrows of Annelides, skeletons and spicula of sponges, small *Orbiculæ*, and the like.

These beds have been studied more particularly than those of Hartfell; but no forms have been detected in addition to those given in the foregoing list, all of which are present in abundance.

The *C.-Wilsoni* zone forms the inferior portion of the partially inverted synclinal of Hartfell Shale visible in the Black Linn of Glenkiln Burn (fig. 19, p. 286). It is beautifully shown on the north side of the trough. It has here a thickness of about 8 feet. The dark flaky shales, though present, appear to be far less abundant than in the two former localities, and there is a simultaneous increase in the amount of grey shale and flagstones. The hard grey ribs seen at Hartfell Spa, but almost absent from the section in Dobb's Linn, are here very numerous, and give to the section generally a marked similarity to those in exposures of the Glenkiln division. The intractable bed at the base of the zone is slightly thicker than usual, and does not exhibit such clear traces of stratification.

Fossils are rare. As usual, they are in a state of half-relief.

The only forms I have collected from the zone at this locality are:—

Dicellograptus moffatensis (?) (*Carr.*).
Dicranograptus Nicholsoni (*Hopk.*).
Climacograptus Wilsoni (*Lapw.*).
Climacograptus Scharenbergi (*Lapw.*).
Diplograptus foliaceus (*Murch.*).

The same zone is exposed at the foot of Fall-Law Score, near Berrybush, at Craigmichan, and at Cramalt Score, in the valley of the Meggat Water. At Craigmichan it is too much shattered to yield fossils. In the other localities they are present, but are comparatively rare.

This zone may be looked upon as marking the age of transition between the two successive formations and life-epochs of Glenkiln and Hartfell. In lithological characteristics it partakes of the peculiarities of both formations. A similar combination is apparent in its included fauna. Every species hitherto detected within the limits of this zone is a survivor from the underlying Glenkiln Shales, while none of the strictly peculiar Hartfell forms have as yet appeared upon the scene. Nevertheless we have unequivocal evidence of the high importance of the unrepresented interval between the period in which the typical Glenkiln fauna was prevalent and that in which these transitional strata were deposited, in the complete absence from the latter of such striking genera as *Cœnograptus* (Hall), *Didymograptus* (M'Coy), *Thamnograptus* (Hall), &c. In addition to these, numerous species belonging to other genera have totally disappeared, such as *Dicranograptus formosus* (Hopk.), *D. ziczac* (Lapw.), *Diplograptus Whitfieldi* (Hall), *D. dentatus* (Brongn.), &c. Even of the forms that have survived, several have been remarkably transformed. *Dicranograptus ramosus* (Hall) has lost its fringe of lateral spines, *Climacograptus bicornis* its basal disk, while *C. cœlatus* has almost certainly been transformed into the form *C. Wilsoni*. Seven of these survivors become extinct within the limits of the zone, or outlive it for an insignificant period, namely—

Climacograptus Wilsoni (*Lapw.*).
—— Scharenbergi (*Lapw.*).
Diplograptus angustifolius (*Hall*).
—— tricornis (*Carr.*).
Glossograptus Hincksi (*Hopk.*).
—— Harknessi (*Nich.*).
Discina, sp.

ii. *Zone of* Dicranograptus Clingani (*Carr.*).—This title is given to the central and most typical mass of the Hartfell Shales. All its strata are of a deep black colour, and there is a total absence throughout of the seams of pale shale and mudstone so common in the neighbouring zones. An additional distinction is furnished by the circumstance that many of its beds are hard and flag-like, forming numerous prominent ribs among the prevailing softer strata. The latter are slaty shales, about one eighth of an inch in thickness. They can be extracted in large plates, are fine-grained, tough, and ring sharply under a blow of the hammer. There is no distinct mineralogical break between this zone and the preceding, nor is it possible to indicate exactly its superior limit. For its base an

arbitrary line is chosen, where the grey ribs and pale seams of the *C.-Wilsoni* zone disappear. Above, it is conveniently limited by the horizon in which *Pleurograptus linearis* (Carr.) and its associates are first detected.

At no single locality within the limits of the Moffat district are the beds of the zone in such a condition as to admit of individual study and admeasurement. Nevertheless it is generally possible to make out the various horizons, and to arrive at a close approximation to the true thickness of the entire zone.

At Hartfell its total thickness is about 22 feet, as measured among the broken beds above the line of the *C.-Wilsoni* zone in the "cornice" in the northern slope of the gorge. In Dobb's Linn 24 feet may perhaps be assigned to it. In the greatly shattered sections in the other localities mentioned it is impossible to estimate its original thickness.

Palæontologically, the most remarkable characteristic of this zone is the fact that fossils are totally absent from many of the beds and are strictly confined to certain horizons, the strata of which do not differ in any appreciable degree from those of the barren beds. On each of these horizons there is found usually a single species or variety, its individuals lying scattered all over the face of the stratum in countless numbers and in the wildest confusion.

At Hartfell three of these horizons are especially conspicuous. The lowest is characterized by the exclusive presence of *Climacograptus caudatus*. It lies about 4 feet above the base of the zone, and recurs again and again in the numerous convolutions of the northern cliffs. The second swarms with *Dicellograptus caduceus* (Lapw.), and is found near the centre of the zone; but as it is restricted to a few inches of the succession it is less easy of recognition. The third includes several neighbouring strata near the summit of the zone. Its peculiar fossil is *Climacograptus styloideus* (Lapw.), which may be collected in abundance at several points in the North Cliff.

The foregoing are peculiar forms, wholly unknown outside the limits of the horizons they distinguish; but there are numerous additional horizons belonging to such long-lived forms as *Dicellograptus Forchhammeri* (Gein.), *D. Morrisi* (Hopk.), *Retiolites fibratus* (Lapw.), &c. &c.

The species occurring within the limits of this zone in the typical section of Hartfell include:—

Leptograptus flaccidus (*Hall*).
Amphigraptus radiatus (*Lapw.*).
Dicellograptus Forchhammeri (*Gein.*).
—— moffatensis (*Carr.*).
—— caduceus (*Lapw.*).
Dicranograptus ramosus (*Hall*).
—— Nicholsoni (*Hopk.*).
—— Clingani (*Carr.*).
Climacograptus bicornis (*Hall*).
—— scalaris (*His.*).
—— ——, var. caudatus (*Lapw.*).
Climacograptus scalaris, var. styloideus (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— truncatus (*Lapw.*).
—— tricornis (*Carr.*).
Lasiograptus margaritatus (*Lapw.*).
Retiolites fibratus (*Lapw.*).
Lingula, sp.
Corynoides calycularis (*Nich.*).
—— curtus (*Lapw.*).
Eurypterus, sp.

In Dobb's Linn the strata of the *D.-Clingani* zone visibly overlie the streaked beds of the *Climacograptus-Wilsoni* zone in the southern angle of the Main Cliff, but they are too much broken and metamorphosed to yield many fossils. The seam with *Climacograptus caudatus* occurs in one of the small scaurs at the bottom of the cliff near its centre, but is much more satisfactorily exposed in the prolongation of the zone up the slope forming the angle between the Long Burn and that descending from the falls. Some distance above it occurs the well-marked seam with *Dicellograptus caduceus*, swarming with its characteristic fossils, and traceable southward at intervals in the Main Cliff, and northward over the summit of the North Cliff, and thence through both the projecting bosses of hard black flagstones in the slope beyond.

All the fossils given in the list from Hartfell have been detected in this zone in Dobb's Linn, together with the additional species :—

Siphonotreta micula (*M'Coy*).	Lingula, sp.
Acrotreta Nicholsoni (*Dav.*).	Eurypterus, sp.

In Glenkiln Burn a portion of this zone occupies the centre of the synclinal of the Black Linn. The seam with *Climacograptus styloideus* is easily detected on the north side of the trough, and, higher up, the horizon of *Dicellograptus caduceus*. The prevalent fossils appear to be :—

Leptograptus flaccidus (*Hall*).	Climacograptus caudatus (*Lapw.*), var.
Amphigraptus radiatus (*Lapw.*).	—— bicornis (*Hall*).
Dicellograptus moffatensis (*Carr.*).	Diplograptus foliaceus (*Murch.*).
—— Forchhammeri (*Gein.*).	Corynoides calycularis (*Nich.*).
Dicranograptus ramosus (*Hall*).	—— curtus (*Lapw.*).
—— Clingani (*Carr.*).	

Many of the same fossils are found in corresponding positions in the zone as exposed at Mount Benger, Syart Score, Fall-Law Score, Moory Syke, and Craigmichan. The last three localities also exhibit its physical relationships to the zones above and below.

iii. *Zone of* Pleurograptus linearis (*Carr.*).—The hard flaggy beds of the *D.-Clingani* zone pass up everywhere by insensible gradations into an overlying group of dark thin-bedded shales. In the lower portions of this new group the shales split easily into thin slate-like sheets, similar to those of the minority of the underlying beds. Higher up they become thicker, softer, and tougher, while among them appear thin seams and bands of barren shale, white or more generally cream-coloured. These increase in number and importance as we ascend, till, finally, they occupy the whole succession, and pass insensibly into the great mass of barren mudstone of the Upper Hartfell Group. Side by side with this change in the lithological character of the strata, there takes place a corresponding alteration in the aspect of their included fossils. In the lowest bands they are mere pyritous stains upon the surface of the laminæ; in the highest they are frequently preserved in the round.

The fossiliferous portion of the zone is best studied at Mount Benger (fig. 16), where two longitudinal faults have isolated the

great majority of the beds of the zone, preserved them from alteration or disturbance, and placed them in such a position that every bed admits of thorough examination. The white bands are here strictly confined to the higher half of the section, the beds of the lower subdivision agreeing in all essential respects with those of the underlying zone. The fossils are given in the following list :—

Leptograptus flaccidus (*Hall*).
—— capillaris (*Carr.*).
Amphigraptus divergens (*Hall*).
Pleurograptus linearis (*Carr.*).
Dicellograptus elegans (*Carr.*).
—— Morrisi (*Hopk.*).
Dicellograptus pumilus (*Lapw.*).
Climacograptus tubuliferus (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— quadrimucronatus (*Hall*).
Retiolites fibratus (*Lapw.*).
Lingula, sp.

Climacograptus tubuliferus is restricted to the lowest portion of the zone as here exposed, which is also distinguished further by the exclusive presence of *Dicellograptus elegans* (Carr.).

In Dobb's Linn the strata of this zone may be followed almost continuously from the southern boundary of the Main Cliff to a point at the head of the Middle Score. The central bands, with *Pleurograptus linearis*, are entire, and yield well-preserved fossils where they are exposed in the Main Cliff; and all the species occurring in the beds at Mount Benger have been collected above the Middle Score.

At Hartfell the beds of this zone are exposed, and are highly fossiliferous at several points in the north slope. Above the "cornice," the central beds, here cut off from the succeeding strata by a small fault, are filled with excellent examples of *Pleurograptus linearis* and its associates. The higher beds, with their included white and cream-coloured seams, occur again and again in the numerous scores that furrow the slope beyond.

These pale-coloured bands become very numerous in the bands above St. Mary's Loch. At Fall-Law Score, Yellow Mire, &c. they appear to have coalesced into a thick bed of soft white mudstone. In the sections of the Moory Syke, Craigmichan, and Belcraig, the underlying fossiliferous bands are more prominently exhibited, and yield occasionally, when less altered than usual, a few of their characteristic Graptolites.

Everywhere this well-marked zone is characterized by the exclusive presence of the peculiar compound genus *Pleurograptus*, which has never yet been detected in any of the fossiliferous strata above or below. Here also do we find for the last time the genera *Leptograptus*, *Amphigraptus*, and *Dicranograptus*, and several species belonging to other genera—*Diplograptus foliaceus* (Murch.), *Dicellograptus Morrisi* (Hopk.), *D. elegans* (Carr.), *Climacograptus tubuliferus*, &c.

(b) *Upper Hartfell.*

The peculiar white or grey seams so prevalent in the upper portion of the preceding zone finally exclude all trace of the asso-

Fig. 28.—*Vertical Section* IV. Upper Hartfell Shale (*Dobb's Linn*).

Shivery shale, black and grey.....	*Diplograptus acuminatus.*
Basal seam of Birkhill Shale, drab-coloured tough shale.....	Crowded with *Climacograptus* in half-relief.
Green shales and mudstone	No fossils.
Seam of soft black shale, pyritous shivery shales, yellow and grey ...	*Diplograptus truncatus.* *Climacograptus bicornis* (*tuberculatus*).
Seam of soft black carbonaceous shale.	*Dicellograptus anceps.* Crowded with *Diplogr. truncatus.*
Yellow and green shivery shales	
Seams of soft black flaky shale, with partings of white and yellow sandy muds, shales, and clays	*Dicellograptus anceps.* *Diplogr. truncatus*, &c.
Thin-bedded light green shivery shales, with a few hard seams of flagstone, slightly calcareous	
	No fossils.
Thick-bedded light green mudstones ...	
Seam of black carbonaceous shale, 2 inches in thickness.....	*Diplograptus, Climacograptus, Dicellograptus.*
Dark grey mudstones, some almost black, with yellow or orange-coloured surface	
	Diplograptus foliaceus.
Soft black flags and shales, with partings of white clay	*Pleurograptus linearis, Diplograptus quadrimucronatus.*
	Dictyonema moffatensis.
Hard slaty shales, black, thin-bedded.	*Pleurograptus linearis, Amphigraptus*, sp., *Diplograptus foliaceus.*

Bo^2. *Zone of* Dicellograptus anceps.

Bo^1. "Barren Mudstone."

Bo^3. *Zone of* Pleurograptus linearis.

(Continued from Vertical Section III.)

ciated black fossiliferous shales, and lead insensibly into the thick overlying mass of pale mudstones constituting the Upper Hartfell Group. As a whole the beds of the group are totally barren of fossils, which are met with only along two widely separated horizons. Here, however, they occur in abundance, and the facies of the fauna thus indicated compels us to assign the containing beds to the same general division as the underlying mass of dark shales.

The most intelligible section of the beds of this subdivision is exhibited in the Main Cliff at Dobb's Linn and in the gully below the falls (fig. 28).

i. *Barren Mudstones.*—The inferior portion of the Upper Hartfell consists here of about 30 feet of light-coloured shales and mudstones. In the lower half of the zone they are arranged in beds of from 6 inches to a foot in thickness; above they form a homogeneous mass of shaly rock with few traces of stratification. The inferior beds weather into slabs of a deep rusty-brown colour; the higher beds into flakes or angular splinters of a light yellow tint.

No fossils are present in any of its beds, except in a thin seam of black shale, about 2 inches in thickness, not far removed from the base of the zone. This swarms with poorly preserved Graptolites, chiefly *Dicellograptus Forchhammeri* (Geinitz), *Climacograptus scalaris?* (His.), *Diplograptus truncatus* (Lapw.).

The same fossiliferous seam can be recognized in the section at the Moory Syke (fig. 9); and there is even a trace of it in the magnificent section of Craigmichan Scaurs.

Intercalated among these "Barren Mudstones" occur several thin courses or ribs of hard compact rock, slightly calcareous, weathering exteriorly of a deep drab or dark brown colour. They have been recognized only in the section at Dobb's Linn.

At Craigmichan the lower and thick-bedded portion is very conspicuous, and the whole zone has expanded to a total thickness of 50 feet; but this may include the representative of the succeeding zone, which is not individually recognizable in the section at that locality.

Nowhere are the Barren Mudstones so conspicuously exhibited as in Belcraig Burn, where they occupy the greater part of the exposure, and display their peculiar characteristics to perfection.

These beds also occur along the Ettrick River at Berrybush and at Hartfell Spa, everywhere under the same general aspect, and everywhere totally barren of fossils.

ii. *Zone of* Dicellograptus anceps (*Nich.*).—At Dobb's Linn the thick mass of the "Barren Mudstones" is surmounted by a thinner group of somewhat similar beds, diversified by seams of black fossiliferous shales and variegated mudstones. The higher division of this overlying group is formed of 6 feet of greenish-grey flaggy shale, non-fossiliferous, and identical in all respects with the typical beds of the "Barren Mudstone." The lower division, which is also about 6 feet in thickness, contains five or six thin seams of carbonaceous shale, soft, fossiliferous, and interbedded with numerous lines of grey,

yellow, or white mudstone, never more than 2 or 3 inches in thickness.

The arrangement of the strata of this well-marked zone has been given already in our description of the physical structure of the ground at Dobb's Linn. (p. 253). The fossils obtained belong exclusively to the species:—

Climacograptus bicornis, var. tuberculatus, *Nich.*	Diplograptus truncatus (*Lapw.*).
—— scalaris (*His.*).	Dicellograptus anceps (*Nich.*).

The same zone is exposed in Riskinhope Burn (fig. 10) under the same general aspect, and yielding the foregoing Graptolites in some abundance; but it is more satisfactorily exhibited in the beautiful section in Black Grain (fig. 12), where the dark seams are very prominent, and the fossils are numerous and well preserved.

§ III. *Birkhill Shales.*

The third or Birkhill division of the Moffat Series comprises all the fossiliferous strata that intervene between the *D.-anceps* zone of the Upper Hartfell Shales and the coarse grits and flagstones of the Gala group. In the typical section of Dobb's Linn, the total thickness of the division is about 140 feet. This thickness is probably exceeded in the district lying to the south of the Moffat valley; but in none of the sections there exhibited are its strata in such an attitude as to admit of exact admeasurement.

In their mineralogical characters the beds of this division, while bearing a decided resemblance to those of the other divisions of the Moffat Series, at the same time possess many marked peculiarities. The dark carbonaceous shales of this division never show the slaty, close-grained texture or the plate-like structure of those of the subjacent Hartfell group. They are normally soft, irregularly laminated, and split under the hammer into small slabs or flakes, with a ridged and uneven surface. The unfossiliferous mudstones are quite as distinct, no longer weathering down into yellow prismoid fragments, but forming thin flag-like sheets of a greyish-green or deep purple colour, and resembling in all their essential features those of the corresponding strata of the succeeding Gala group.

The physical peculiarities of the rocks of the Birkhill division are accompanied by far more important distinctions in the facies of its included fauna. Of the numerous genera of compound Graptoloidea which gave such a varied character to the fauna of the Glenkiln Shales, and many of which have accompanied us in our upward progress into the typical beds of the Hartfell division, not one passes up into the Birkhill Shales. Here, on the other hand, the extraordinary prevalence of Monograptidæ upon every zone is in striking contrast to what occurs in the inferior division, where not the slightest trace of any form of this family has ever been detected.

The two genera *Monograptus* and *Rastrites* swarm abundantly in

all except the lowest zone of the Birkhill Shales, and with the more sparingly distributed genera *Diplograptus*, *Climacograptus*, and *Retiolites* (together with a few scattered forms of Crustacea and Spongidæ) constitute the whole of the fossils of the group. Consequently, while there is no falling off in respect of individuals or even species (many of the beds bearing favourable comparison with the most prolific "horizons" of the Hartfell Shales), yet, when contrasted with that afforded by the preceding divisions, the fauna of the Birkhill Shales is strangely monotonous throughout. No better proof could perhaps be adduced of our having clearly overstepped the limits of the great Llandeilo-Bala formation, where the Graptolithina attain their maximum, and that we are now almost on the threshold of those Upper Silurian rocks where these strange old creatures disappear from our sight for ever.

It will be superfluous to enumerate all the localities where this division is exposed. This has been done already to a large extent in the stratigraphical portion of the paper. As it immediately underlies the greywackes, some of the zones of the group are necessarily exposed in every spot where the Moffat Shales are visible, the extent of our acquaintance with its strata and fossils increasing in direct proportion as we approach its highest limit. It will be sufficient for our purpose to define the characters of its successive zones in some of the more symmetrical and fossiliferous sections, and, at the same time, to indicate a few of the additional sections where these facts may be verified and supplemented.

(a) *Lower Birkhill.* (Fig. 29.)

The thickness of this subdivision in the typical section of the Main Cliff is about 60 feet. It is made up almost wholly of black carbonaceous shales, occasionally diversified by intercalated seams of variegated mudstones. The *general* lithological and palæontological features of the subdivision have been already so frequently dwelt upon, that it is only necessary in this place to give a brief summary of the characteristics of its three component zones.

i. *Zone of* Diplograptus acuminatus (*Nich.*).—At the base of the inferior subdivision of the Birkhill Shales lies a mass of shivery shales, black- or blue-hearted, and weathering down into thin flakes, superficially of a bright yellow colour. The basal seam of this band is about 6 inches in thickness, consisting of a tough, flag-like shale, slightly calcareous (see fig. 28). It is of a deep drab or gingerbread colour where it is affected by the weather, and it yields numerous fossils in admirable preservation. The details of the various sections of this zone in Dobb's Linn may be gathered from our description of the rocks of that locality. Its commonest fossils are *Diplograptus acuminatus* (Nich.), *D. vesiculosus* (Nich.), rare, *Climacograptus scalaris* (His.), *Dimorphograptus elongatus* (Lapw.). The same physical characters mark this zone at Thirlstane Score, Scabcleuch, and Belcraig. At the last-named locality it affords the same fossils. In the broken section at Hartfell *Diplograptus acuminatus* occurs in some abund-

Fig. 29.—*Vertical Section* V. Lower Birkhill Shale (*Dobb's Linn*).

*Cb*¹. *Zone of* Diplograptus cometa (continued on Section VI.)	*Diplograptus cometa, D. tamariscus.*
	Monograptus lobiferus.
Grey flaggy shale	
*Ca*³. *Zone of* Monograptus gregarius.	Conspicuous seam of white clay with calcareous nodules.
Upper Division.	Fossils abundant and well preserved.
Black flaggy shales, with seams of white, grey, and yellow clay	
	Monograptus leptotheca, M. concinnus, M. communis, M. lobiferus, Diplograptus folium, D. tamariscus, Climacograptus, Discinocaris Browniana, Dawsonia campanulata, &c.
Seam of calcareous nodules.....	
Soft shivery aluminiferous shales	
Concretionary band	
	Rastrites peregrinus, Monograptus gregarius, M. fimbriatus, Diplograptus physophora.
Hard black shales, with partings of white, yellow, blue, or purple clay...	
Conspicuous seam of calcareous nodules in coloured clays.....	*Monograptus triangulatus* in profusion.
Lower Division.	
Black flaggy shales, with coloured clay partings.....	*Monograptus Sandersoni, M. cyphus, M. gregarius.*
	Diplograptus physophora, D. tamariscus.
Seam of calcareous nodules.....	
Hard black shales, with lines of white clay	*Climacograptus innotatus.*
	Climacograptus normalis.
Seam of calcareous nodules.....	
Hard flaggy shales, with white partings.....	*Diplograptus modestus, Monograptus tenuis, M. attenuatus, Climacograptus innotatus.*
*Ca*². *Zone of* Diplograptus vesiculosus.	
Thick-bedded black carbonaceous shales and flagstone, with a few inconspicuous partings of soft, coloured clays	Crowded along a few horizons with *Diplograptus vesiculosus, Climacograptus innotatus, C. normalis, Monograptus tenuis, M. attenuatus, Dawsonia*, sp., ? *Discinocaris*, sp.
*Ca*¹. *Zone of* Diplograptus acuminatus.	*Diplograptus acuminatus, Dimorphograptus elongatus, &c.*

(Continued from Vertical Section IV.)

ance; but neither there nor in the great section at Craigmichan Scaurs can the zone be identified with certainty.

ii. *Zone of* Diplograptus vesiculosus (*Nich.*).—This zone with its hard thick-bedded black flagstones, everywhere so prominent among the surrounding strata and so doggedly resistant of those atmospheric influences that have crumbled the underlying shales to powder, has been so frequently alluded to in the foregoing pages as to preclude any special description in this place. Next to the typical section at Dobb's Linn it is exposed in the Score above Thirlstane Burn, and in the fine section at Belcraig. Strictly speaking, it everywhere merges imperceptibly into the lowest beds of the succeeding zone, which possess corresponding lithological characters and yield, generally speaking, the same fossils.

The fauna of the *D.-vesiculosus* zone at Dobb's Linn includes the following species, which occur in abundance on a few distant horizons, the intervening beds being wholly destitute of organic remains:—*Diplograptus vesiculosus* (Nich.), *Climacograptus scalaris* (His.), *C. innotatus* (Nich.), *Monograptus tenuis* (Portl.), *M. attenuatus* (Hopk.), *Dimorphograptus elongatus* (Lapw.).

iii. *Zone of* Monograptus gregarius (*Lapw.*).—The flags of the *D.-vesiculosus* zone graduate upwards into a great succession of black flags, shales, and mudstones. Among them abound seams and beds of coloured clay or mudstone, blue, grey, purple, or black. These are much softer than the flaggy rock, and are worn down into deep grooves and channels on the face of every section. At intervals occur bands and lines of nodules of calcareous ironstone, forming prominent ribs and ridges, rising conspicuously amid the more tractable beds around. The whole group abounds with iron pyrites, either included in the shales themselves, or forming seams and bunches of bright yellow concretions and crystals. The waters that trickle over these beds take up this mineral in their course, streaking and staining the whole mass of beds of a deep rusty yellow with a subsequent deposit of oxide of iron.

At Dobb's Linn a bed of concretionary and calcareous ironstone, near the centre of the zone, forms a convenient boundary between its lower and upper divisions. Below that line the dark carbonaceous shales are hard and flag-like, and show few of the coloured courses. Above it the beds are thinner, and the mudstone bands are excessively numerous. The lower division is here 20 feet in thickness, and the lower 15 feet. This thickness is greatly in excess of that of any of the remaining zones of the Birkhill Shales; and it will also be seen that the fauna is larger and more varied. There can be no doubt, however, that these beds constitute one single physical mass, which, neither mineralogically nor zoologically, is it possible satisfactorily to subdivide.

This group stands related to the main mass of the Birkhill formation in a corresponding position to that occupied by the zone of *Dicellograptus Clingani* with respect to the Hartfell Shales. It embraces, namely, a large proportion of the most distinctive beds of the formation and includes a majority of its most characteristic fossils.

Below the central nodule-band the commonest species are :—

Rastrites peregrinus (*Barr.*).
Monograptus Sandersoni (*Lapw.*).
—— cyphus (*Lapw.*).
—— tenuis (*Portl.*).
—— communis (*Lapw.*).
—— triangulatus (*Harkn.*).
—— gregarius (*Lapw.*).
Monograptus concinnus (*Lapw.*).
Diplograptus tamariscus (*Nich.*).
—— vesiculosus (*Nich.*).
—— physophora (*Nich.*).
—— modestus (*Lapw.*).
Climacograptus innotatus (*Nich.*).

Above the nodule-band many of these recur and are associated with :—

Monograptus leptotheca (*Lapw.*).
—— lobiferus (*M'Coy*).
Dawsonia campanulata (*Nich.*).
Discinocaris Browniana (*Woodw.*).
Diplograptus folium (*His.*).
—— insectiformis (*Nich.*).

Some of these forms have a very restricted vertical range in the beds of this zone. *Monograptus Sandersoni* (Lapw.) and *M. fimbriatus* (Nich.) are unknown above the central line. *Monograptus triangulatus* (Harkn.) occurs only in the neighbourhood of the nodule-band. Neither *Rastrites peregrinus* nor *Diplograptus vesiculosus* reach the summit of the group.

All the localities noted as exhibiting the black and variegated beds of this zone afford also, as a rule, their characteristic fossils. Nowhere is it possible to point out any marked distinction between these beds at Dobb's Linn and their representatives elsewhere, except, perhaps, along the southern band of Ettrick and Glenkiln, where they are usually greatly hardened, have a somewhat slaty structure, and show only a small proportion of the variegated mudstones.

In the last three or four feet of the beds of this zone, as exposed at Birkhill and in the Thirlstane Score, we have evidence of the commencement of those conditions which led to the production of the thick overlying mass of grey flags, in the presence of numerous hard seams of grey shale intercalated among the normal fossiliferous dark shales and mudstones. The terminal beds afford always the best-preserved fossils of the zone, but they are rare and of few species.

(b) *Upper Birkhill.* (Fig. 30.)

The finest and, in many respects, the most typical section of this subdivision is seen in the gorge and corrie immediately below the falls of Dobb's Linn. It here embraces about 77 feet of barren grey flaggy mudstones, and includes three distinct groups or horizons of black fossiliferous shales. The base of the group appears well-defined, being marked by a sudden lithological break. Actually, however, its first fossiliferous zone has little to distinguish it from the underlying beds. The grey shales near the summit of the group become harder and more flag-like as we ascend the succession, and there is an almost insensible lithological transition into the basement beds of the great greywacke formation of the Gala group. From the circumstances of the case, the final line of demarcation is neces-

Fig. 30.—*Vertical Section* VI. Upper Birkhill Shale (*Dobb's Linn*).

Flagstones and greywackes of the Gala group	
*Cb*³. *Zone of* Rastrites maximus.	
Grey flaggy shales, 15 ft. (curtailed)...	No fossils.
Grey flags	
Soft black-shale seam, weathering yellow-edged	
Grey flaggy shale	3 ft.
Seam of hard flaggy black shale	*Rastrites maximus, Monograptus Halli.*
White-clay seam	1 ft.
Soft black pyritous shale, concretionary	*Rastrites maximus, M. Halli, M. spinigerus, M. Hisingeri, Diplograptus Hughesi,* &c. in partial relief.
White clay, with calcareous nodules...	
Grey flaggy shales, seams of white clay with concretions, and scattered lines of dark carbonaceous and pyritous mudstone	Few fossils.
Thin line of hard black slaty shale ...	
*Cb*². *Zone of* Monograptus spinigerus.	
Soft sandy shales, with rough or reticulated surface	
Hard black shale	*Monograptus spinigerus, M. Hisingeri, M. intermedius.*
Soft sandy pale shale	
Hard flaggy black shale, with cuboidal fracture	*Monograptus tenuis, Diplograptus Hughesi.*
Bed of soft highly pyritous black shale	Crowded with *Monograptus spinigerus, Monograptus Hisingeri,* &c.
Hard bands of black shale, parted by lines of white clay	
Rusty brown shivery or splintery shales	*Monograptus spinigerus, M. Hisingeri, M. tenuis, Diplograptus sinuatus, D. tamariscus, D. folium,* &c.
Soft slaty shales, with greyish-brown or indigo-coloured surface	
Band of black shale	Seam covered with trails of Annelides &c.
White clay, with nodules	Fossils numerous and well preserved: *Monograptus Clingani, M. crenularis, Rastrites hybridus, Diplograptus sinuatus.*
Black shale	
Grey shales, with seams of white clay.	
*Cb*¹. *Zone of* Diplograptus cometa.	
Soft flaky aluminiferous black shales...	*Diplograptus cometa, D. tamariscus, Monograptus lobiferus, M. cyphus,* &c.
Conspicuous seam of white clay (concretions)	

(Continued from Vertical Section V.)

sarily an arbitrary one. It is drawn at the point where the first bed of greywacke is seen in the section.

Our attention has been already directed to the peculiar seams of white clay which form so striking a feature in the section of the beds of this subdivision in the locality under description. They are nowhere so remarkably conspicuous as at this spot, but they are never wholly absent in any single exposure throughout the whole of the southern portion of the Moffat district.

It is clear from a comparison of the numerous sections of these beds that the black bands increase in thickness and importance in proportion as we pass across the district to the southward. To the north they rapidly thin out, disappearing wholly in the sections along the bands of Hartfell, Headshaw, Douglas, and Meggat. There the grey beds form a single mass of barren rock, unrelieved by any intercalated fossiliferous seam whatsoever. In this direction they change gradually into a sheet of thin-bedded flagstone differing in no way from similar beds clearly interbedded with the typical greywackes of the Gala group.

Hence it is highly probable that the line marking the summit of the Moffat Series is actually drawn along slightly different horizons in the different sections. Within the limits of the present district, however, the error can be but slight, and its effect upon our conclusions of no great moment.

i. *Zone of* Diplograptus cometa.—This name is given to the first eight feet of the Upper Birkhill Shales of Dobb's Linn. The lower portion of the zone is formed of four feet of barren grey flagstone (see fig. 29); the upper portion of a similar thickness of soft black shales, weathering down into shivery fragments coated with the oxide of iron. Lithologically the zone appertains to the Grey-Shale group; palæontologically its affinities are with the underlying Black-Shale series. Its fossils are poorly preserved at this locality. The only forms collected by myself are:—

Rastrites capillaris (*Carr.*).
Monograptus lobiferus (*M'Coy*).
—— leptotheca (*Lapw.*).
—— cyphus (*Lapw.*).
—— tenuis (*Portl.*).
—— Hisingeri (*Carr.*).
Diplograptus cometa (*Gein.*).
Diplograptus tamariscus (*Carr.*).
—— sinuatus (*Nich.*).
—— folium (*His.*).
—— Hughesi (*Nich.*).
Climacograptus scalaris (*His.*), var. normalis (*Lapw.*).

The same bed appears to be exposed at Craigierig, Back Burn, in the sections in the lower portion of Selcoth Burn below Craigmichan Scaurs, &c. Beyond its value as a well-defined mineralogical horizon in the section at Dobb's Linn, the zone is of very insignificant importance in the Birkhill division.

ii. *Zone of* Monograptus spinigerus (*Nich.*).—Whatever misgivings may be felt as to the propriety of erecting the *D.-cometa* band into a distinct zone, not a moment's doubt can be entertained of the great importance of the group of strata which immediately succeeds it. Not only is its distinctness evident from the presence of several

species of Graptolithina unknown in the earlier zones, but the marked mineralogical characteristics of several of its component beds and their remarkable persistence throughout the district compel us to assign it a special title.

In the "corrie" at Dobb's Linn the section of the group under consideration, though unfortunately somewhat dislocated, clearly shows a lower division of 15 feet of barren grey rock, and an upper division of 10 feet of black shales and white mudstones.

In the very centre of the lower division of barren grey shales occurs a double seam of black shale crowded with well-marked fossils, principally:—

Rastrites hybridus (*Lapw.*).
Monograptus Clingani (*Carr.*).
—— runcinatus (*Lapw.*).
—— leptotheca (*Lapw.*).
Diplograptus folium (*His.*).
—— tamariscus (*Nich.*).
—— Hughesi (*Nich.*).
Climacograptus scalaris (*His.*).

Monograptus Sedgwicki (*Portl.*) = spinigerus (*Nich.*).

The total thickness of the dark seams on this horizon is about six inches. In the beds immediately in contact with them we meet with laminæ reticulated with the trails of Annelides, and dotted with peculiar rounded protuberances.

The upper division of the zone includes at least six distinct seams of black shale. Some of these are hard and weather into irregular cuboidal pieces. Others are soft, pyritous, and yield beautifully preserved Graptolites. These black flags are divided from each other by thin seams of white mudstone or pale sandy shales. The latter are in several respects the most characteristic strata in the zone. Here they are too greatly shattered and weathered to allow us properly to appreciate their distinctive peculiarities. Elsewhere, however, they are seen to be of a light cream-colour, of a sandy texture, and with a rough harsh surface. Occasionally the latter is cut up into small lozenge-shaped patches by hundreds of fine straight grooves, rarely empty, but almost invariably filled up by quartz or pyrites.

The fauna of these black shales already recognized by myself at this locality includes the following forms:—

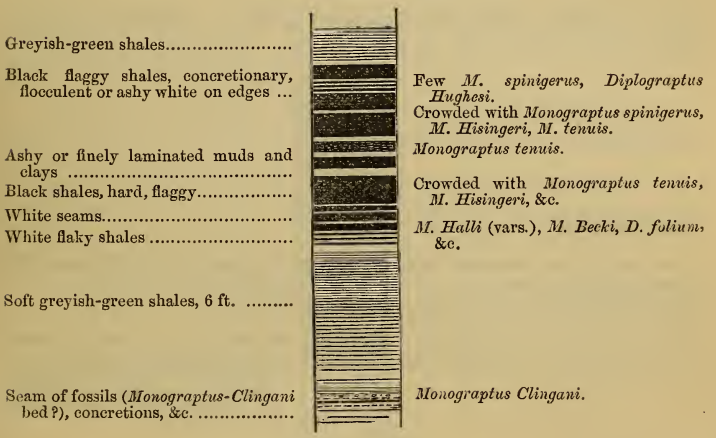
Rastrites hybridus (*Lapw.*).
Monograptus proteus (*Barr.*).
—— spinigerus (*Nich.*).
—— Hisingeri (*Carr.*).
—— attenuatus (*Hopk.*).
—— intermedius (*Carr.*).
—— Becki (*Barr.*).
Diplograptus folium (*His.*).
Diplograptus sinuatus (*Nich.*).
—— tamariscus (*Nich.*).
Retiolites perlatus (*Nich.*).
Diplograptus Hughesi (*Nich.*).
Dawsonia, sp.
Discinocaris Browniana (*Woodw.*).
Peltocaris aptychoides (*Salt.*).
Ceratiocaris, sp. ind.

In the fine section of this zone at the Moory Syke (fig. 9, p. 270), the pale sandy beds are more perfectly exhibited than in the Dobb's Linn corrie, and there is also a more satisfactory exposure of the dark shale with *Monograptus spinigerus*,

beautiful specimens of which occur in abundance. The peculiar double black seam of the lower division of the zone also occurs in a corresponding position at Thirlstane Burn, retaining fully its mineralogical characteristics and its distinctive fossils.

The best section of the beds of the *M.-spinigerus* zone is that of Eldinhope Burn in the valley of the Yarrow, where every seam is capable of exact admeasurement. It will be seen from the accompanying diagram how perfectly the beds at this spot agree with the preceding description. The double seam with *Monograptus Clingani* (Carr.) forms the base of the section, and the overlying beds of barren shales are more than a foot thicker than at Dobb's Linn (fig. 31).

Fig. 31.—*Zone of* Monograptus spinigerus (Nich.). (*Eldinhope Burn.*)



Beds belonging to this zone are visible also in Thirlstane Score (fig. 8, p. 269), Riskinhope, Muckra, Duffkinnel, &c. Everywhere they yield fossils of the list given above and none other. Everywhere, from Sundhope to Glenkiln, the seam of soft pyritous mudstone affording the spinose variety of *M. spinigerus* is the most prolific stratum, swarming with innumerable Graptolites in admirable conservation.

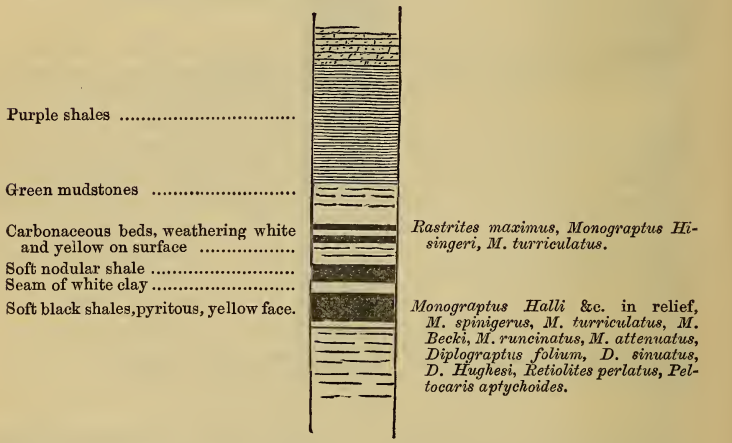
iii. *Zone of* Rastrites maximus (*Carr.*).—The concluding zone of the Moffat Series embraces the final 25 feet of shaly strata seen in the typical exposure at Dobb's Linn. Its fossils are restricted to what may conveniently be termed two pairs of black beds, separated by three feet of barren shale. The lowest bed is nearly two feet in thickness, the second about a foot, the third a few inches, and the fourth a mere line. The zone contains many of the white-clay bands, and the strata immediately in contact with the fossil beds weather of a bright yellow colour.

The fossils are generally in a state of low relief, and include :—

Rastrites maximus (*Carr.*).
Monograptus Halli (*Barr.*).
—— turriculatus (*Barr.*).
—— proteus (*Barr.*).
—— runcinatus (*Lapw.*).
—— intermedius (*Carr.*).
—— Becki (*Barr.*).
Monograptus spinigerus (*Nich.*).
—— Hisingeri (*Carr.*).
—— attenuatus (*Hopk.*).
Diplograptus folium (*His.*).
—— Hughesi (*Nich.*).
Retiolites perlatus (*Nich.*).

In Thirlstane Burn (fig. 32) the six feet of grey shale overlying the highest pair of black beds has increased to eight feet, and changed to a deep purple colour. Both pairs of black seams are here recognizable of the same relative thickness as at Dobb's Linn. The intervening three feet of green shale has, however, dwindled down to one foot. Every fossil given in the foregoing list occurs here, and in addition some peculiar sponges.

Fig. 32.—*Zone of* Rastrites maximus (*Carr.*). (*Thirlstane Score.*)



At Mount Benger the two pairs of black beds are separated by six feet of barren shale, and the fossiliferous seams are not individually recognizable. Their fossils, however, are easily obtained in abundance.

In Craigmichan only the highest pair of black beds is visible, and the barren mudstones which separate it from the greywackes have again decreased to their original six feet of thickness. The few fossils obtained here are preserved in relief in carbonate of copper, and the barren shales are stained of a deep purple hue.

The only fossils collected here are :—

Rastrites maximus (*Carr.*).
Monograptus spinigerus (*Nich.*).
—— Halli (*Barr.*).
Monograptus runcinatus (*Lapw.*).
Diplograptus folium (*His.*).

In the beautiful section at Belcraig Burn four feet only of grey

shale intervene between the highest black bed of the zone and the first of the greywackes. The two pairs of fossiliferous seams split up into several subordinate beds, and are separated only by a bed of barren shale a foot in thickness. The fossils are of similar species to those cited from Craigmichan, but there occur in addition :—

Monograptus turriculatus (*Barr.*).	Monograptus Hisingeri (*Carr.*).
—— proteus (*Barr.*).	Retiolites perlatus (*Nich.*).
—— Becki (*Barr.*).	Peltocaris aptychoides (*Salt.*).

In the highest exposure at Glenkiln the *Rastrites-maximus* zone may be recognized at the base of a cliff of purple flagstone overhanging the stream. Its beds are exposed in a conspicuous rocky projection washed by the waters of the burn.

The highest seam of black shale is here divided from the first flaggy greywacke of the cliff by two feet only of non-fossiliferous purple mudstone. The upper pair of black beds are represented by a foot and a half of soft aluminiferous black shale, containing a few fragmentary Graptolites. The lower pair are represented by a bed of dark flaggy shale twice as thick as the former, and separated from it by two and half feet of barren mudstone.

The fossils of this lower bed collected by myself include *Rastrites maximus* (Carr.), *Monograptus spinigerus* (var.), *M. Halli* (Barr.), *M. runcinatus* (Lapw.).

There are several additional exposures of the *R. maximus* zone to the south of the line of the Moffat valley. The most important of these are the sections of Crosscleuch, Muckra, Whitehope, Black Grain, and Entertrona.

To the north of the Moffat valley, if we except the doubtful beds at the summit of the Moffat Shales of Garple Burn, the zone is not recognizable.

In the annexed Table the letters used bear the following signification :—

c. Commmon.
C. Very common
r. Rare.
V. Very rare.

Table showing the Vertical Distribution of the Fossils of the Moffat Series.

List of Species.	GLENKILN.	HARTFELL.					BIRKHILL.						Foreign localities.
		LOWER.			UPPER.		LOWER.			UPPER.			
		Zone of *Clim. Wilsoni.*	Zone of *Dicr. Clingani.*	Zone of *Pleur. linearis.*	Barren muds.	Zone of *Dicell. anceps.*	Zone of *Dipl. acuminatus.*	Zone of *Dipl. vesiculosus.*	Zone of *Mon. gregarius.*	Zone of *Dipl. cometa.*	Zone of *Mon. spinigerus.*	Zone of *Rastr. maximus.*	
Rastrites maximus, *Carr.*	...	...	...	...	...	...	...	...	...	...	...	C	*Lobiferus*-beds (Sweden).
—— capillaris, *Carr.*	...	...	...	...	...	...	...	...	...	...	...	R	land).
—— hybridus, *Lapw.*	...	...	...	...	...	...	...	...	...	r	C	...	Coniston Mudstones, Coalpit Bay (Ire-
—— distans, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	R	Coniston Muds., Kieselschiefer.
—— peregrinus, *Barr.*	...	...	...	...	...	...	...	...	C	R	...	...	Coniston Muds., Kieselschiefer, Colonies, *Lobiferus*-beds, Coalpit Bay.
Monograptus turriculatus, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	R	Coniston Mudstones, Colonies, *Lobiferus*-beds, Tieveshilly (Ireland), Lisbellaw.
—— Halli, *Barr.*	...	...	...	...	...	...	...	...	...	...	R	c	Coniston Muds., Colonies, *Retiolites*-beds (Sweden), Tieveshilly beds, Kieselschiefer.
—— Hisingeri, *Carr.*	...	...	...	...	...	...	...	...	...	...	C	c	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— Becki, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	C	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— spinigerus, *Nich.* (=Sedgwicki, *Portl.*).	...	...	...	...	...	...	...	...	...	...	C	R	Coniston Muds., Colonies, Kieselschiefer, Pomeroy beds.
—— proteus, *Barr.*	...	...	...	...	...	...	...	...	...	R	R	R	Coniston Muds., Colonies, Kieselschiefer, Tieveshilly beds, *Retiolites*-beds.
—— runcinatus, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	c	*Lobiferus*-beds.
—— concinnus, *Lapw.*	...	...	...	...	...	...	...	...	r	r	...	...	Coniston Mudstones, Coalpit-Bay beds.
—— argutus, *Lapw.*	...	...	...	...	...	...	...	...	r	r	r	...	Coniston Muds., Coalpit-Bay beds.
—— intermedius, *Carr.*	...	...	...	...	...	...	...	...	...	...		R	Coniston Mudstones.
—— Clingani, *Carr.*	...	...	...	...	...	...	...	...	...	...	r		
—— spiralis, *Geinitz*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— communis, *Lapw.*, var.	...	...	...	...	...	...	...	...	C	...	...	...	Coniston Muds., Coalpit-Bay beds.
—— fimbriatus, *Nich.*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Mudstones.

Monograptus gregarius, *Lapw.*	...	...	...	...	...	...	...	...	C	c	...	...	Coniston Mudstones, Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit Bay.
—— attenuatus, *Hopk.*	...	...	...	...	...	...	...	r	r	r	r	r	Coniston Muds., Colonies, Kieselschiefer, Coalpit-Bay beds.
—— tenuis, *Portl.*	...	...	...	...	...	...	...	r	C	c	c	c	Coniston Muds., Kieselschiefer, Pomeroy, Coalpit Bay.
—— lobiferus, *M'Coy*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Muds., Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— cyphus, *Lapw.*	...	...	...	...	...	...	...	...	C	...	...	...	Coniston Muds., Kieselschiefer, Coalpit-Bay beds.
—— leptotheca, *Lapw.*	...	...	...	...	...	...	...	...	r	r	...	...	Coniston Mudstones, Kieselschiefer (?).
—— Sandersoni, *Lapw.*	...	...	...	...	...	...	...	...	r	...	...	...	*Lobiferus*-beds, Coalpit-Bay beds.
—— triangulatus, *Harkn.*	...	...	...	...	...	...	...	...	c	...	...	...	Pomeroy, Kieselschiefer, Coalpit Bay, *Lobiferus*-beds.
Dimorphograptus (?) elongatus, *Lapw.*	...	...	...	...	...	...	r	r					
Diplograptus folium, *His.*, = palmeus+ovatus, *Barr.*	...	...	...	...	...	...	...	...	c	c	c	c	Coniston Mudstones, Colonies, Kieselschiefer, *Lobiferus*-beds, Pomeroy beds, Coalpit-Bay beds.
—— sinuatus, *Nich.*	...	...	...	...	...	...	...	...	...	c	c	c	Coniston Mudstones, Coalpit-Bay beds.
—— Hughesi, *Nich.*	...	...	...	...	...	...	...	...	c	c	c	c	Coniston Mudstones, Coalpit-Bay beds.
—— tamariscus, *Nich.*	...	...	...	...	...	...	...	...	C	c	c	c	Coniston Mudstones, *Lobiferus*-beds, Coalpit-Bay beds.
—— physophora, *Nich.*	...	...	...	...	...	...	...	...	R	...	...	...	Kieselschiefer (?).
—— vesiculosus, *Nich.*	...	...	...	...	...	...	...	C	r	...	...	...	Coniston Mudstones, Coalpit-Bay beds.
—— acuminatus, *Nich.*	...	...	...	...	...	...	C	...	...	...	...	...	Kieselschiefer (?).
—— truncatus, *Lapw.*	...	r	C	C	C	C	...	...	...	...	...	...	Utica Slate.
—— quadrimucronatus, *Hall*	...	...	...	c	...	...	...	...	...	...	...	...	Utica Slate, *Dicranograptus*-beds, Conway.
—— foliaceus, *Murch.*	C	C	C	c	...	...	...	...	...	...	...	...	Conway, Tiddyn Dicwm, Abereiddy B., *Dicranograptus*-beds, Carnalea beds (Ireland), Utica Slate, Norman's Kiln (H. R. G.).
—— angustifolius (*Hall*)	r	...	...	...	...	...	...	...	...	...	...	...	Upper Skiddaw, Norman's Kiln, Ballygrot.
—— tricornis, *Carr.*	c	c	...	...	...	...	...	...	...	...	...	...	Abereiddy Bay, Ballygrot beds, Skiddaw slates, Norman's Kiln.
—— dentatus, *Brongn.*	r	...	...	...	...	...	...	...	...	...	...	...	Skiddaw Slates, Point Levis, Llanvirn.
—— Whitfieldi, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm.
—— cometa, *Geinitz*	...	...	...	...	...	...	...	...	...	C	...	...	Kieselschiefer, *Lobiferus*-beds.
—— insectiformis, *Nich.*	...	...	...	...	...	...	...	...	R				
—— penna, *Hopk.*	...	...	...	...	...	...	...	...	R(?)				[*ferus*-beds.
—— modestus, *Lapw.*	...	...	...	...	...	...	...	c	R	...	...	...	Coniston Mudstones, Coalpit Bay, *Lobi-*

List of Species.	GLENKILN.	HARTFELL.					BIRKHILL.						Foreign localities.
		LOWER.			UPPER.		LOWER.			UPPER.			
		Zone of *Clim. Wilsoni.*	Zone of *Dicr. Clingani.*	Zone of *Pleur. linearis.*	Barren muds.	Zone of *Dicell. anceps.*	Zone of *Dipl. acuminatus.*	Zone of *Dipl. vesiculosus.*	Zone of *Mon. gregarius.*	Zone of *Dipl. cometa.*	Zone of *Mon. spinigerus.*	Zone of *Rastr. maximus.*	
Diplograptus perexcavatus, *Lapw.*...	r	r	...	...	...	...	...	...	...	...	...	...	*Dicranograptus*-schists, Ballygrot.
Lasiograptus Harknessi, *Nich.*	r	r											
—— margaritatus, *Lapw.*	...	...	r										
—— ? bimucronatus, *Nich.*.....	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln (?), Tiddyn Dicwm.
Glossograptus Hincksi, *Hopk.*	r	r	...	...	...	...	...	...	...	...	...	...	? Norman's Kiln, Tiddyn Dicwm.
Clathrograptus cuneiformis, *Lapw.*	r												[Coalpit-Bay beds.
Retiolites perlatus, *Nich.*	...	...	...	...	...	...	...	...	?	r	r	r	Coniston Mudstones, *Lobiferus*-beds,
—— fibratus, *Lapw.*	...	...	r	r									
Climacograptus scalaris, *His.*.....	...	...	...	...	...	...	...	...	...	...	...	...	Coniston Mudstones, Kieselschiefer, *Lobiferus*- and *Retiolites*-beds, Coalpit-Bay beds, Pomeroy beds.
—— ——, var. normalis, *Lapw.* ...	...	...	...	...	...	?	C	C	C	c	c	c	
—— ——, var. rectangularis, *M'Coy*	...	...	...	...	...	...	...	...	c	...	...	...	Coalpit Bay, Colonies, Kieselschiefer.
—— ——, var. styloideus, *Lapw.*...	...	...	...	R									
—— ——, var. caudatus, *Lapw.* ...	...	...	c										
—— ——, var. tubuliferus, *Lapw.* .	...	...	...	c									
—— cælatus, *Lapw.*	c	...	...	...	...	...	...	...	...	...	...	...	Oslo beds (Norw.), *Dicranograptus*-schists.
—— Wilsoni, *Lapw.*	...	c											
—— bicornis, *Hall*	C	c	c	?	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm, Builth.
—— ——, var. peltifer, *Lapw.*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
—— ——, var. tridentatus, *Lapw.* .	r	r											
—— ——, var. tuberculatus, *Nich.* .	...	...	...	...	...	c							
—— Scharenbergi, *Lapw.*	c	c	...	...	...	...	...	...	...	...	...	...	Abereiddy Bay, Tiddyn Dicwm, Llany Chevmedd, Oslo beds, *Dicranograptus*-schists.
—— innotatus, *Nich.*	...	...	...	...	...	...	...	r	r				
Leptograptus flaccidus, *Hall*	r	r	c	C	...	...	...	...	...	...	...	...	Lake St. John, Conway, Abereiddy Bay?
—— capillaris, *Carr.*	...	...	...	r									

Pleurograptus linearis, *Carr.*	...	...	...	C									
Amphigraptus divergens, *Hall*	...	...	...	r	...	...	...	...	...	...	...	...	Lorraine Shale (Utica Slates).
—— radiatus, *Lapw.*	...	?	r										[? Tiddyn Dicwm.
Cœnograptus gracilis, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, *Dicranograptus*-schists,
—— explanatus, *Lapw.*	R												
—— surcularis, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
—— nitidulus, *Lapw.*	R												[Tiddyn Dicwm.
Didymograptus superstes, *Lapw.*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, *Dicranograptus*-schists,
—— serratulus, *Hall* (?)	R	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
Dicellograptus anceps, *Nich.*	...	...	...	...	...	C	...	...	...	...	...	...	*Trinucleus*-schists (Sweden).
—— Morrisi, *Hopk.*	...	...	c	C	...	...	...	...	...	...	...	...	*Dicranograptus*-schists, Conway.
—— Forchhammeri, *Geinitz*	r	r	C	?	?	...	...	...	...	...	...	...	Abereiddy Bay, Llandridod, Tiddyn Dicwm, Bornholm, *Dicranograptus*-schists.
—— elegans, *Carr.*	...	...	...	c									
—— divaricatus, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Llanvirn.
—— moffatensis, *Carr.*	r	r											
—— caduceus, *Lapw.*	...	...	r										
—— pumilus, *Lapw.*	...	...	...	r									[Llandridod, Tiddyn Dicwm.
—— sextans, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Abereiddy Bay ?,
Dicranograptus Clingani, *Carr.*	...	...	r	...	...	...	...	...	...	...	...	...	*Dicranograptus*-beds.
—— ramosus, *Hall*	R	?	c	...	...	...	...	...	...	...	...	...	Tiddyn Dicwm, Builth, Conway.
—— Nicholsoni, *Hopk.*	c	c	c	...	...	...	...	...	...	...	...	...	Tiddyn Dicwm, Montmorenci Falls.
—— formosus, *Hopk.*	R												
—— ziczac, *Lapw.*	c												
Thamnograptus typus, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm.
—— scoticus, *Lapw.*	R												
Corynoides calycularis, *Nich.*	c	c	c	...	...	...	...	...	...	...	...	...	Conway.
—— curtus, *Lapw.*	...	...	c	...	...	...	...	...	...	...	...	...	*Dicranograptus*-schists.
—— gracilis, *Hopk.*	...	...	?										
Dictyonema moffatensis, *Lapw.*	...	...	R										
Dawsonia campanulata, *Nich.*	...	...	...	...	...	...	...	...	c	c	c	R	
Acrotreta Nicholsoni, *Daws.*	...	...	R										
Discina, sp.	r	r											
Lingula, sp.	R	R											
Siphonotreta micula, *M'Coy*	...	...	R										
Peltocaris aptychoides, *Salt.*	...	...	...	...	...	...	...	...	...	...	R	R	
Aptychopsis Lapworthi, *Woodw.*	...	...	...	...	...	...	...	...	...	...	...	R	
Discinocaris Browniana, *H. Woodw.*	...	...	...	...	...	...	...	...	r	r	r		
Eurypterus, sp.	...	...	R										
Asaphus, sp.	R												

C. Conclusion.

§ I. *Systematic Importance of the Divisions of the Moffat Series.*

The black carbonaceous and ferriferous strata of the Moffat Series have often been compared to the thin-bedded argillaceous deposits, impregnated with iron and stained with vegetable matter, that bulk so largely in our British Coal-measures. It is, indeed, impossible to avoid this comparison. The rapid alternation of thin flaggy layers of nodular ironstone and carbonaceous and partially calcareous strata give to many of its sections* (especially those of the Birkhill division) a remarkable resemblance to hundreds that may be pointed out in the higher division of the Carboniferous system. These resemblances descend even to minute peculiarities. One of the most striking is the frequent association of a seam of black shale with a band of white or cream-coloured clay, which has been very aptly instanced† as reminding the observer of a coal-seam and its subjacent argillaceous floor or "under-clay."

Several mining speculators, relying solely upon these mineralogical resemblances, have sought in vain for coal in these beds. To the geologist they have been equally misleading. Accustomed to the rapid recurrence of strata of this nature in a great mass of sandstone rock, and finding, as it appeared, a similar arrangement almost everywhere throughout the Silurians of the south of Scotland, he could not fail to draw the inference that these black beds occurred upon several horizons in an enormous mass of arenaceous deposits.

In the case of the miner, an acquaintance with the geological position of the fossils of the carbonaceous shales would have effectually prevented his foolish expenditure of time and labour. Similarly, in the case of the geologist, it is our present knowledge of the vertical range of the fossils of the Moffat Shales which, above all other testimony, proves their identity in character, sequence, and physical relationships in every locality, clearing away at a single stroke most of the difficulties that formerly barred the path of the investigator, and rendering his task in the future a matter of ease and certainty.

Moreover it has shown conclusively that, beyond their superficial lithological resemblances, the Moffat Series have no features in common with the argillaceous and ferriferous Carboniferous strata with which they are usually compared. The Coal-measures were manifestly accumulated under what, geologically speaking, were rapidly varying physical conditions. Beds precisely similar recur again and again in the succession. The fauna remains unaltered through enormous thicknesses of rock, the same species reappearing invariably upon the resumption of similar physical conditions. On the other hand, the Moffat Rocks, though composed merely of a few hundreds of feet of black and variegated shales and mudstones, rarely or never show two bands that are precisely similar; nor do they anywhere throughout the succession in the present district afford the slightest evidence of hasty deposition. The collective

* Mem. Geol. Surv. Scotland, Explan. Sheet iii. pp. 11, 12.
† *Ibid.* Explan. Sheet iii. p. 11.

fauna, again, is even more strikingly contrasted. Although composed throughout of the same zoological groups, it shows a continued and most important change in its aspect as we follow it from the base to the summit of the formation. Not a single species is known to range through more than half its total thickness. Nowhere is there any adequate apparent cause for this extraordinary effect. Nowhere is there any reason for doubting that it is due to those gradual and cumulative changes brought about in every extended period of time.

In their general mineralogical features, and in their rapid variation in palæontological characteristics, the rocks of the Moffat Series are very different from any of the typical Silurians of the Principality. Among Palæozoic formations the only strata with which in these respects they admit of satisfactory comparison are the dark shales imbedding the calcareous rocks of Scandinavia, where the enormously thick Silurians of Wales are represented by less than 2000 feet of fossiliferous rock, and where each fossil has but a few feet of vertical range. Among Secondary deposits they may be paralleled with such formations as the Speeton Clay of the coast of Yorkshire, where the massive Upper Jurassic and Neocomian rocks of the Continent and the south of England are represented by less than 500 feet of dark shales and clays, in which each zone is marked by its peculiar Ammonite, and each fossil ranges through but a small fraction of the entire succession.

If these analogies are allowed their due weight (and every new fact gathered in the Moffat district adds something to their force), they inevitably lead to the deduction that the Moffat Rocks are the greatly attenuated representatives of enormous thicknesses of the Welsh Silurians, in which their fossils will be found to have a vastly extended range. In other words, there is a high probability that the *Divisions* of the Moffat Series have, in truth, a systematic importance equal, or at least approximating to that of the so-called formations of Siluria.

§ II. *Comparison of the Faunas of the three Divisions of the Moffat Series with those of their Foreign Equivalents.*

Owing to the great rarity in the Moffat Series of fossils belonging to the well-understood families of the Brachiopoda and Crustacea, which are universally regarded as the most trustworthy exponents of the geological age of their containing beds, we are forced to rely almost exclusively upon such evidence as may be afforded by their Graptolithina. In our comparative ignorance of the relationships and vertical distribution of the forms composing this peculiar group, all testimony derived from this source would, formerly, have been either wholly ignored by the geologist, or received with grave suspicion. Within the last few years, however, a sufficiency of evidence has gradually been accumulated, which places it beyond a doubt that these fossils are quite as restricted in their geological distribution as those of the better understood zoological groups. In the face of the complete, and indeed overwhelming, proofs of the truth of this fact, which follow from their vertical arrangement in the different

zones of the Moffat Series, as detailed in the preceding portion of this paper, all reference to the identical results arrived at in other districts by British and continental palæontologists would here be superfluous.

That none of the Moffat Shales are of Arenig age is clear from the complete absence within them of those complex forms of *Dichograpti* and *Phyllograpti* which constitute so striking and characteristic a feature of the Graptolitic fauna of the Skiddaw Slate and its Welsh and Canadian equivalents. That none of them appertain to the true Upper Silurian, as at present understood by the majority of geologists, is fully as evident, from the fact that they are similarly destitute of all the known peculiar Upper Silurian forms. Our search for their extra-Scottish equivalents must therefore be restricted to the three successive formations of the Llandeilo, Bala, and Lower Llandovery. Let us pass the respective Graptolite faunas of these in review.

(a) *Llandeilo Formation* (*Llandeilo-Flags of* Murchison).

From the valuable and accurate papers of Mr. Hicks*, and the general results of the special study of the Welsh Graptolites made by Mr. John Hopkinson, we learn that the Llandeilo beds of South Wales, in the typical localities of Llandridod, Meadow Town, and Abereiddy Bay, have afforded the following species :—

Leptograptus flaccidus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
Dicranograptus ramosus (*Hall*).
—— formosus (*Hopk.*).
Diplograptus foliaceus (*Murch.*).
—— dentatus (*Brongn.*).
—— tricornis (*Carr.*).
Climacograptus cælatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).

The general facies of this assemblage is clearly that of the Glenkiln Shales, in which all the foregoing species are abundant, and to which in South Scotland many are strictly peculiar. In South Wales, however, they are almost invariably associated with forms of *Didymograptus* of the type of *D. Murchisoni*, and sometimes with species of *Phyllograptus*, none of which have ever been detected in the Moffat Series.

In one locality among the Llandeilo beds of North Wales these distinctive forms are absent. The dark shales in the hills a few miles to the north of Tremadoc, which have been mined for copper, but whose precise position is yet undetermined, have afforded to Messrs. Salter† and Hopkinson‡ the following species, all of which are common Glenkiln forms :—

Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
Dicanograptus ramosus (*Hall*).
Cœnograptus gracilis ? (*Hall*).
Diplograptus foliaceus (*Hall*).
—— ? Whitfieldi (*Hall*).
Diplograptus ? Hincksi (*Hopk.*).
—— tricornis (*Carr.*).
Climacograptus bicornis (*Hall*).
—— Scharenbergi (*Lapw.*).
Didymograptus superstes (*Lapw.*).
Thamnograptus typus? (*Hall*).

Judging from the absence of *Didymograptus Murchisoni* and of the genus *Phyllograptus*, and the presence of some of the succeeding Bala

* Quart. Journ. Geol. Soc. vol. xxi. pp. 180 &c.
† Mem. Geol. Survey, vol. iii. plate xi. fig. 1.
‡ Coll. John Hopkinson, Esq.

forms, it may be inferred that this band of dark shale and therefore the Glenkiln Shales themselves are of the Upper or highest Llandeilo age.

This inference is greatly strengthened by the facts obtainable in the Llandeilo strata of Central Sweden, where the greater portion of the Llandeilo formation of Britain is represented by the well-known Orthoceras-Limestone. Upon this limestone reposes the sheet of dark shales denominated by Dr. Linnarsson* the Middle Graptolitic Schists. The lowest beds of this deposit, which, according to Törnquist, are most intimately associated with the underlying limestone, afford abundant examples of *Phyllograptus* and the *Murchisoni*form species of *Didymograptus*. These, however, soon disappear, and the highest beds that can be satisfactorily assigned to the Llandeilo formation afford the strikingly peculiar Glenkiln forms:—

Didymograptus superstes (*Lapw.*).	Climacograptus Scharenbergi (*Lapw.*).
Cœnograptus gracilis (*Hall*).	—— perexcavatus (*Lapw.*).

But it is on the continent of North America that we meet with the most complete representatives of the Glenkiln Shales. The dark shales and flagstones that bound the valley of the Hudson in the neighbourhood of the city of Albany were originally assigned by American geologists†, on imperfect data, to the Lorraine and Utica-Slate formation (Cincinnati Group), which everywhere overlies the Trenton Limestone. Their geographical position, their perfect agreement in rapid convolution and amount of alteration with the neighbouring Quebec (Taconic) Rocks, together with the comparatively ancient facies of the small group of fossils they afford, force us to regard them rather as forming the highest division of the so-called Quebec Group, whose greatly disturbed beds are believed by Professor Sterry Hunt‡ and others to emerge unconformably from below the horizontal Trenton Limestones. On this view the Hudson-River Shales stand in the place of the higher Llandeilo beds of Britain.

At Norman's Kiln, in the Valley of the Hudson, on the Marsouin River, on the Lower St. Lawrence, and elsewhere they yield Graptolites in some abundance. From the figures and descriptions of Professor Hall the palæontologist can easily identify the following Glenkiln species§:—

Dicellograptus sextans (*Hall*).	Diplograptus foliaceus (*Murch.*).
—— divaricatus (*Hall*).	—— angustifolius (*Hall*).
Cœnograptus gracilis (*Hall*).	Climacograptus bicornis (*Hall*).
—— surcularis (*Hall*).	Thamnograptus typus (*Hall*).
Dicranograptus ramosus (*Hall*).	Didymograptus serratulus (*Hall*).
Diplograptus tricornis (*Carr.*).	—— superstes (*Lapw.*).
—— Whitfieldi (*Hall*).	Corynoides calycularis (*Nich.*).

Even the peculiar Glenkiln species absent from these American strata are represented by intimately allied forms. Thus:—

* Linnarsson, MS. Compare also Dr. Törnquist, Œfvers. af K. Vet.-Akad. Förhandlingar, 1871.

† Emmons's Amer. Geol. vol. i. p. 47.

‡ Hunt, 'Chemical and Geological Lectures.'

§ Prof. Hall, 'Palæont. New York,' vol. i. pls. 72 and 73, vol. iii. pp. 495 *et seq.*; Grapt. Quebec Group, p. 54.

Glossograptus Hincksii is represented by		Glossograptus ciliatus (*Emm.*).
Dicranograptus ziczac	,, ,,	Dicranograptus furcatus (*Hall*).
Climacograptus Scharenbergi	,,	Climacograptus scalaris (*His.*).
Clathrograptus cuneiformis	,,	Clathrograptus Geinitzianus (*Hall*).

Thus, if the evidence from fossils be appealed to as indicative of the geological age of the Glenkiln division, the facts already adduced point unequivocally to a position in the Llandeilo formation as at present understood. The complete absence of the *Didymograpti* of the type of *D. Murchisoni*, and of the genus *Phyllograptus*, so common in the lower beds of that formation in Wales and Sweden, compels us to assign it to the very highest division of the Llandeilo, immediately at or not far below the base of the Caradoc or Bala.

(b) *Bala or Caradoc.*

The Upper Llandeilo age of the Glenkiln Shales having been thus definitely settled, we naturally turn to the strata of the succeeding Bala formation in search of the Graptolites of the Hartfell Shales.

Unfortunately for our purpose, it happens that in Siluria and the greater part of North Wales the rocks of this formation are of too arenaceous a character to afford Graptolites. In one locality only are they yet known to occur in comparative abundance, viz. in the cliffs to the N.W. of the town of Conway, where Mr. Hopkinson has collected *:—

Leptograptus flaccidus (*Hall*).	Corynoides calycularis (*Nich.*).
Diplograptus quadrimucronatus (*Hall*).	Dicranograptus ramosus (*Hall*).
—— truncatus (*Lapw.*).	—— Nicholsoni (*Hopk.*).
—— foliaceus (*Murch.*).	Dicellograptus Forchhammeri (*Gein.*).
	—— Morrisi (*Hopk.*).

In Sweden the lowest beds of the Bala formation are represented by the highest division of Linnarsson's *Dicranograptus*-schists, which contains the following Hartfell species †:—

Dicellograptus Forchhammeri (*Gein.*).	Diplograptus foliaceus (*Murch.*).
—— Morrisi (*Hopk.*).	—— quadrimucronatus (*Hall*).
Dicranograptus ramosus (*Hall*).	Corynoides calycularis (*Nich.*).
—— Clingani (*Carr.*).	—— curtus (*Lapw.*).

In North America, as is well known, the higher Bala beds are represented by the Lorraine and Utica Shales (Cincinnati Group) that everywhere overlie the Trenton Limestone. They afford the common Hartfell forms ‡—

Leptograptus flaccidus (*Hall*).	Dicranograptus ramosus (*Hall*).
Amphigraptus divergens (*Hall*).	—— Nicholsoni (*Hopk.*).
Diplograptus foliaceus (*Murch.*).	Diplograptus quadrimucronatus(*Hall*).
—— truncatus (*Lapw.*).	

None of the foregoing species have ever been met with in beds of Lower Llandovery age, and only three or four in the Upper Llandeilo, viz. those species which are also common to the Glenkiln and Hartfell Shales of Moffat. Thus the palæontological evidence of

* Coll. Mr. Hopkinson. Compare also Mem. Geol. Survey, vol. iii. pl. xii. fig. 1.

† Coll. Dr. Linnarsson.

‡ Nicholson (Collection); Hall, Grapt. Quebec Group, pp. 143, 144; Hall, Pal. New York, vol. iii. Supp. fig. 509; Logan, Geol. of Canada, p. 200.

the age of the Hartfell beds, though less perfect than that obtainable with respect to the underlying division, nevertheless places it beyond a doubt that they stand in the place of some of the Bala beds of Siluria.

(c) *Lower Llandovery.*

The Lower Llandovery rocks of Wales, in which the fossils of the third division of the Moffat Series might be expected to occur, have not as yet been thoroughly searched for Graptolites; nor has a single species of the Birkhill fauna been hitherto recorded from any of the Silurians of the principality.

In the Lake-district, however, the Coniston Mudstone, which occupies a corresponding stratigraphical position above the representatives of the Bala Limestone, is crowded with Graptolites. At Skelgill and Knock it yields the following Birkhill forms*:—

Rastrites hybridus (*Lapw.*).
—— peregrinus (*Hall*).
—— distans (*Lapw.*).
Monograptus turriculatus (*Barr.*).
—— Halli (*Barr.*).
—— cyphus (*Lapw.*).
—— communis (*Lapw.*).
—— fimbriatus (*Nich.*).
—— lobiferus (*M'Coy*).
—— Hisingeri (*Carr.*).
—— gregarius (*Lapw.*).
Monograptus attenuatus (*Lapw.*).
—— spiralis (*Gein.*).
—— tenuis (*Portlk.*).
—— argutus (*Lapw.*).
Diplograptus vesiculosus (*Nich.*)
—— tamariscus (*Nich.*).
—— Hughesi (*Nich.*).
—— sinuatus (*Nich.*).
—— folium (*His.*).
Retiolites perlatus (*Nich.*).
Climacograptus normalis (*Lapw.*).

It is needless to insist upon the precise agreement of this fauna with that of the Scottish deposit in question.

Nor is this agreement less striking when the comparison is made with the faunas of the Graptolitiferous Llandoveries of the continent of Europe. It will be seen from the Table inserted in my brief memoir on the Scottish Monograptidæ (Geol. Mag., Dec. 1876) that the Kieselschiefer of Thuringia, placed by Murchison and others at the junction of the two Silurians, afford almost all the Birkhill fossils, and that many of them are found in the "Colonies" which bridge over the palæontological gap between the Lower and Upper Silurians of Bohemia.

In the *M.-lobiferus* beds, which form the inferior division of Dr. Linnarsson's Upper Graptolite Schists and overlie every thing in Sweden to which the name Bala can be applied, the strictly Birkhill assemblage occurs which is given below†:—

Rastrites maximus (*Carr.*).
—— peregrinus (*Barr.*).
Monograptus lobiferus (*M'Coy*).
—— Hisingeri (*Carr.*).
—— spiralis (*Gein.*).
—— triangulatus (*Harkn.*).
—— Sandersoni (*Lapw.*).
—— spinigerus (*Nich.*).
Monograptus runcinatus (*Lapw.*).
—— gregarius (*Lapw.*).
Diplograptus folium (*His.*).
—— tamariscus (*Nich.*).
—— modestus (*Lapw.*).
—— cometa (*Geinitz*).
Climacograptus scalaris (*His.*).
Retiolites perlatus (*Nich.*).

Not one of these species descends into the underlying limestones

* Nicholson, Quart. Journ. Geol. Soc. vol. xxiv. pls. xix., xx., &c.
† Linnarsson (Collection). See also Törnquist, Œfvers. af K. Vet.-Akad. Förhandl. 1874, no. 4, p. 26.

and schists of Bala age, and only a few survive into the overlying *Retiolites*-beds (Mayhill?).

Similar facts might be cited from Brittany, Spain, Ireland, &c., but no further evidence is required to prove that the Birkhill Shales are of Lower Llandovery age.

§ III. *General Conclusions regarding the Age, Geological Relationships, and Conditions of Deposition of the Three Divisions of the Moffat Series.*

1. The evidences actually at our command regarding the vertical distribution of the fossils of the Moffat Series in the Silurian rocks of Europe and America thus conclusively establish the high systematic importance of its three main divisions, already deduced by us from their general lithological and palæontological characteristics. The three faunas which in South Scotland are characteristic of the three successive *Divisions* of the Moffat Series prove to be elsewhere as strikingly characteristic of the three successive *formations* that form the upper portion of the Cambro-Silurian system.

2. At the same time it cannot fail to be noticed that the vertical distribution of the Graptolithina among the Silurian rocks of the southern portion of Britain, Scandinavia, Central Europe, and North America agrees exactly in all the common forms, species for species, with that worked out by us in our detailed study of the black shales of the Moffat district. We are thus furnished with a complete palæontological demonstration of the truth of our interpretation of the geological succession in the Moffat Series.

3. In future the Glenkiln Shales must be considered as the equivalents of the highest division of the Llandeilo formation of Siluria; the Hartfell Shales as the attenuated representatives of the Bala or Caradoc formation; and the Birkhill Shales as standing in the place of the Lower Llandovery.

The lower portion only of the Hartfell Shales appears to be represented among the extra-Scottish Graptolitiferous deposits, and invariably by strata inferior in geological position to the Bala Limestone. If this be true, the Upper Hartfell Shales must occupy approximately the place of the Bala Limestone of Wales and its foreign equivalents.

The Birkhill Shales have been shown to belong to the lower half of the Middle Silurian (Llandovery formation of Murchison). If, therefore, the plan of making the Upper Silurian commence at the base of the Lower Llandovery, as advocated by Sir Charles Lyell, Mr. Hicks, and others, be generally adopted, the line of demarcation between the Hartfell and Birkhill Shales must form the uppermost limit of the Lower or Cambro-Silurian of the south of Scotland.

4. It may be objected by those who are familiar with the Upper Llandeilo, Bala, and Lower Llandovery formations of Wales, where each of these formations is composed of several thousands of feet of varied rock-matter, and characterized by a very diversified fauna, that it is highly improbable that they can have so degenerated in the insignificant geographical interval which divides Siluria from the south of Scotland, as to be represented in the latter region only by

three thin rock-bands, each about a hundred feet in thickness, almost inseparable mineralogically, and destitute of all traces of their former inhabitants beyond a few Graptolites and Phyllopoda.

There is, however, a complete answer to this objection. The Lower Llandovery, of such vast extent in Cardigan and Merioneth, has dwindled down to the thickness of the Birkhill Shales in the intervening area of the Lake-district, where it forms the Coniston Mudstones, a group of beds almost identical in thickness, lithology, and palæontology with the equivalent Scottish deposit of the Birkhill Shales.

The Caradoc formation of Siluria, estimated by Murchison as above 6000 feet in thickness in the typical area of Shropshire, is reduced to less than half these dimensions in the Berywn Hills of Merioneth. Here, also, it begins to take on the mineralogical characters of the Hartfell Shales, its lower beds, according to Prof. Jukes, becoming more and more of the nature of black slate as we approach the town of Conway*. In the Lake-district the whole formation appears to be represented by less than 300 feet of calcareous shales.

The same attenuation most certainly takes place also in the underlying formations. The diversified Upper Llandeilo formation (of Murchison), consisting in the typical areas in South Wales of several thousands of feet of schist, sandstones, and limestone, is represented in the Berwyns and Arenigs by a homogeneous sheet of dark shales of no great vertical extent. As we approach the shores of the Irish Sea the formation has so thinned out as no longer to be individually recognizable, the Lingula-flags, Tremadoc, Arenig, Llandeilo, and Bala being all possibly included in the contracted sections between the summit of Snowdon and the Lower Cambrian beds to the east of Caernarvon.

Nor is this extraordinary north-westerly attenuation of the Lower Silurian rocks a phenomenon exclusively confined to Britain. On the contrary, it is one of the most striking features of the Lower Silurians of Europe in general. In Bohemia and Brittany, as well as in Siluria, the Lower Silurian rocks are known to be of enormous vertical dimensions, consisting everywhere of highly arenaceous strata, rarely exhibiting any trace of true limestones. Further to the northward, viz. in Bornholm and the Baltic provinces of Russia, they have all dwindled to a thickness of less than a thousand feet of impure limestones and schists. In Sweden and Norway, to the extreme north-west, these limestones rapidly thin away, till finally nothing remains but a few calcareous zones imbedded in a sheet of dark Graptolite-schist †.

* Jukes and Geikie's 'Manual of Geology,' 1872, p. 536.

† We have an excellent illustration of the same fact in the Moffat district itself. Each of the higher zones of the Moffat Series retains all its characteristics absolutely unaltered when followed along the strike of the beds from N.E. to S.W., but varies to a most remarkable extent in its successive reappearances in the sections visible in the direction of the dip. The same rule holds good even among the overlying greywackes to such a degree that several geographical zones are recognizable, each with a distinct lithological character, and each traceable in the line of strike from sea to sea.

In brief, the vertical dimensions, lithology, and palæontology of the Lower Silurian rocks of Western Europe and Britain are practically invariable when the beds are followed in a N.E. and S.W. direction; while they change simultaneously, and to a large but progressive extent, in all these characters when they are traced from south-east to north-west. The geologist, therefore, aware of these facts, might safely have inferred *à priori* that the Llandeilo, Bala, and Lower Llandovery deposits of the south of Scotland, which lie in the general line of strike of the Scandinavian Silurians, would, in all probability, resemble them in their essential features. This, as we have seen, is undoubtedly the case; and the Moffat Series can therefore no longer be regarded as in any way anomalous. On the contrary, they are very naturally defined as British Silurians of the Scandinavian type, being simply the south-westerly prolongation of the sheet of dark Graptolitic schist, of whose vertical continuity the prolific Lower Silurian Limestone bands of Sweden are brief and local interruptions.

5. The consideration of the physical and zoological relationships of the rocks of the Moffat Series to those of the equivalent Silurians of Girvan, the Lake-district, and the north of Ireland is best deferred till the exposures in the Lammermuirs, Leadhills, and Galloway have been described in detail and all the facts are before us. Nevertheless it is perhaps allowable in this place to call attention to the highly significant facts of the remarkable lithological homogeneousness and insignificant vertical thickness of the Moffat Series in the district already described, together with the perfect identity in type of its successive faunas, so clearly distinct specifically. For these facts there appears to be but one common explanation. They point almost irresistibly to the conclusion that these strata must have been laid down in an area removed in some way from the irregular and disturbing influences of river-deposits and current-action, and in which the general physical conditions of the sea-bed remained practically unaltered from the middle of the Llandeilo to the close of the Lower Silurian epoch.

§ IV. *Bearing of the foregoing Conclusions upon the general Question of the Succession among the Lower Silurian Rocks of the South of Scotland.*

It only remains in conclusion to indicate as briefly as possible the bearing of the foregoing results upon the general question of the succession among the Lower Silurians of the south of Scotland.

In this connexion it is highly satisfactory to observe not only that our conclusions appear to be in complete accordance with all the facts universally admitted among those who have made these rocks a subject of special study, but that at the same time they furnish us with a thorough elucidation of many strange anomalies which have hitherto sorely perplexed the cautious investigator.

(*a*) All the black bands yet detected among the Scottish Silurians contain fossils of identical species and varieties with those afforded by one or other of the zones of the Moffat Series, as described in the

foregoing pages, while these fossils are distinct from those in the surrounding greywackes. Bearing in mind the rigid vertical restriction of these fossils to definite zones both in the Moffat Series and in their foreign equivalents, it is impossible to doubt that each and all of these black bands are due to the repetition of the same deposit of the Moffat Shales.

(*b*) Recollecting further the fact of the rapid north-westerly attenuation of the Lower Silurians in Britain and Western Europe, together with that of the gradual disappearance of the highest zones of the Birkhill beds when the latter are followed in a corresponding direction even within the limited area of the Moffat district, we cannot fail to perceive that upon each consecutive repetition the Moffat Series should diminish in collective thickness, and that its fossiliferous zones should disappear one by one from above, as we pass over the Uplands from south-east to north-west.

I shall show upon a future occasion that this is what does actually take place. In the Dobb's-Linn band, as we have seen, all the zones are present. In the Meggat and Hartfell bands, a few miles to the north-west, the highest zone has disappeared. At Bogrie, yet further in the same direction, a few feet only of the *D.-vesiculosus* and *M.-gregarius* bands are all that remain to represent the great Birkhill division of our typical area. On the next reappearance of the series to the north of Dalry, the Birkhill division has wholly disappeared, and the *Pleurograptus*-zone of the Lower Hartfell Shale is almost in contact with the greywackes. The same rule holds good to the extreme north-west limit of the Uplands, where scarcely any thing more than a greatly degenerated representative of the Hartfell-Glenkiln division is apparent.

(*c*) This furnishes us with a clue to a paradoxical circumstance, hitherto perfectly unaccountable to the palæontologist, and puzzling alike to those who held the theory of the identity in geological age of the various black bands, and those who preferred rather to consider those to the northward as belonging to a newer formation than the Moffat series—namely, that as we pass from south to north, the fauna of the black bands, instead of remaining comparatively unaltered, or affording evidence of a gradual change into one of a more modern type, undergoes, on the contrary, a rapid and most peculiar impoverishment. In the southern district, though Bala-Llandeilo forms are certainly present, those characteristic of extra-Scottish Llandovery beds are distinctly predominant. In the central areas the Llandovery forms have all disappeared, and the commonest forms are those of Bala age; while to the extreme north, and therefore in what at first sight appear to be the highest beds, few remain but what are universally admitted to be strictly Llandeilo species.

(*d*) As no fossils of older date than those of the lowest or Glenkiln division of the Moffat Series have ever been discovered in the Southern Uplands, while the base of that division is nowhere visible*, it may be regarded as almost certain that the strata of the black

* The Girvan district is here regarded as a distinct and separate area.

bands everywhere emerge from below the surrounding greywackes in anticlinal forms, as in the Moffat district. If this be the case, all the greywackes that floor the Uplands from St. Abb's Head to the Mull of Galloway necessarily belong to one and the same great arenaceous group, which must be of newer date than the Moffat Series, and therefore, generally speaking, of Llandovery age.

This conclusion is in exact accordance with what is already known of the fauna of the arenaceous deposits to the north of the Moffat area. Though the facts are somewhat complicated by the replacement in the Girvan area of the dark beds of the Moffat Series by limestones and breccias containing Bala and even Llandeilo fossils, yet in the intervening districts of Peebles, Leadhills, and Moniave, where the Hartfell and Glenkiln divisions are still recognizable, it has been clearly shown by the officers of the Geological Survey of Scotland that the conglomerates nearly at the base of the greywacke group are often crowded with fossils (Corals, Crustacea, and Brachiopoda) of well-known Llandovery types.

To the south of the Moffat district this agreement is even more striking. The great greywacke group to the south of the Ettrick was proved by us, in the earlier portion of this paper, to repose upon the Birkhill (Lower Llandovery) Shales of the Moffat Series. After undergoing innumerable repetitions among the desolate wilds of Eskdalemuir, in the contorted and inverted attitudes of their equivalents in the Moffat area, the beds of this great group gradually roll over to the southward, and pass up steadily, by a conformable and gradual lithological and organic transition, into the *Riccarton Beds* of Kirkcudbright, Mosspaul, and the Slitrig, which are acknowledged on all hands to be the representatives of the Wenlock Shale of Siluria.

(*e*) Geologists have long been aware of the presence of a chain of enormous volcanos in the Lake-district of the north of England, which vomited forth mountain-masses of lava and ashes throughout the greater portion of the Llandeilo epoch. Those who accepted the theory of the Llandeilo age of the dark shales and greywackes of the south of Scotland, and attempted to correlate them with their supposed equivalents on the south of the Solway, have frequently expressed their astonishment that these Scottish deposits, which must have been laid down in a sea in some places less than 30 miles distant from the volcanic area of the Lake-district, yet showed no trace whatever of contemporaneous igneous action, whether in the form of trap-dyke, lava-flow, or bed of volcanic ash.

Our conclusion that the oldest beds of the south of Scotland (the Glenkiln Shales) are in reality the equivalents of the highest Llandeilo rocks, read in conjunction with the recent determination of the absence of the highest Llandeilos in the Lake-district owing to the break between the Borrowdale and Coniston groups, as worked out by Mr. Aveline and the officers of the Geological Survey, rids us at once of this vital difficulty. It is not only possible, but indeed highly probable, that the volcanic series of Cumberland are represented by similar rocks in the south of Scotland. They are,

however, at present buried almost everywhere beneath strata of later age, the lowest visible formation (the Glenkiln Shales) succeeding the volcanic series in point of time, and filling up the interval which is unrepresented in the Lake-district.

(*f*) In fine, the facts and inferences detailed in the present paper lead us step by step to the important conclusion that the Lower Silurian rocks of the Southern Uplands are actually arranged in two distinct formations, namely, a lower and very thin group of fine-grained Graptolitic Shales, and an upper and comparatively massive series of arenaceous strata. The latter, though not in reality of extraordinary thickness, is so excessively plicated that it floors more than three fourths of the entire Silurian area, the underlying black shales being visible only at rare intervals along the axes of a few of the more important folds.

Here, then, for the first time, do we begin to realize the fulfilment of the confident prediction of Sir Roderick Murchison, that these apparently interminable Silurian rocks would be found to be, in truth, of reasonable dimensions. The great arenaceous Llandeilo formation of the earlier geologists has utterly vanished, and in its stead we find a few hundreds of feet of argillaceous shales. The Bala beds are proved to be related to those of the underlying formation in identity of lithological character and in physical conformity, as everywhere in Britain and Western Europe generally, where their natural relations have not been disturbed by an excess of igneous activity. We have, indeed, become unexpectedly aware of the presence of a more than ordinary thickness of Middle Silurian rocks; but even these may be satisfactorily paralleled with equivalent strata of corresponding vertical dimensions in the long misunderstood areas of Cardigan and the Thüringer Wald.

EXPLANATION OF PLATES XI.–XIII.

Plate XI.

General maps, showing the geographical distribution of the rocks of the Moffat Series in the typical area of the Moffat District.

Plate XII.

Map and sections of the Moffat rocks of the typical locality of Dobb's Linn, Moffatdale.

Plate XIII.

Plans of the chief exposures of the Black Shales of the Moffat District.

Discussion.

Mr. Warington W. Smyth inquired as to the great break described by the author as occurring at the limestone shown in the sections, where it appeared that above the limestone there were forty or fifty species which do not extend downwards, and below it forty or fifty species which do not pass up. He wished to know whether this indicated a real break in the life of the period, or whether it was due to imperfect investigation of the deposits.

Mr. Hicks remarked on the evident difficulty of the ground investigated, and said that, without the combination of the thorough knowledge of Graptolites and the keen perception of petrological characters possessed by the author, such an explanation of its structure as was given in his paper would have been impossible. He remarked that the great folds described were not uncommon in Silurian countries, and that the succession of rocks described was similar to, if not identical with, that occurring in Wales and in the Lake-district. The break at the Coniston Limestone indicates a change in the physical history of the earth at that period, and is the first break we know of after the commencement of the Cambrian.

Mr. Carruthers remarked that many years ago he had been thoroughly acquainted with the district described, and had pointed out that the Graptolites in this region were of very local occurrence, and often strictly confined to particular beds; but his geological knowledge was not at the time sufficient to warrant him in attempting to work out the stratigraphical results of his observations. From his knowledge of the district, however, he felt convinced that the author had offered a most simple and satisfactory explanation of its excessively complicated structure. He thought that in Mr. Lapworth's paper we shall obtain a base-line for the correlation of all the Silurian beds of the south of Scotland.

Prof. Ramsay wished to indicate that there was another side to the question. Prof. Geikie and his assistants in the Geological Survey of Scotland had observed the occurrence of the black shales referred to; but in Lanarkshire they recognized the existence of a set considerably higher in the series than the Moffat shales, and separated from them by a considerable thickness of shales and grits. In Shropshire and Wales there is a great leap from the Caradoc to the Upper Llandovery, and it seemed to him that part of the Scotch beds, which contain a remarkable mixture of Lower and Upper Silurian Mollusca, might represent the deposits missing in the more southern area.

Prof. Judd remarked that only by such careful and detailed palæontological investigations as those of the author was it possible to hope to find a key to the true succession of strata so folded, crumpled, and broken up as those of the Silurians of the South of Scotland.

Prof. Hughes pointed out that if Mr. Lapworth got the whole series in one continuous section, as indicated on the wall, it was extremely improbable that great grits should be intercalated close

by. He did not know the district, but the interpretation put upon the section by Mr. Lapworth agreed very well with what we should expect from the manner in which the May-Hill beds of S. Wales die out and, where we should expect them in N. Wales, the Corwen Grits, Tarannon Shales, and black bands come in, succeeded by the Denbigh Flags; and then, nearer Moffat, in the Lake-district, an almost exactly similar series, but more like the Moffat section, with abundant fossils in the black bands similar to those associated with the Tarannon Shales of N. Wales. These, which were the Graptolithic Mudstones of the Lake-district, he recognized in Mr. Lapworth's Birkhill group. To complete the story, in Scandinavia, on the other side of Mr. Lapworth's sections, we have the whole series represented by from 250 to 1000 feet; yet the details are very similar. Having, by a question, obtained from Mr. Lapworth the opinion that the strongest break in the Moffat series was at the base of the Birkhill group, which, by the association of fossils elsewhere, seemed to be the equivalent of the Lower Llandovery, he pointed out that we have here additional evidence in favour of bracketing the Upper and Lower Llandovery together, and taking them as the base of the Silurian.

The Author regretted that in the limited time at his disposal he had been unable to lay before the meeting more than a small fraction of the physical and palæontological evidence upon which his conclusions were founded. If, however, it was conceded that the typical sections had been correctly interpreted, and that the succession of organic forms therein was in precise agreement with that in England and Europe, much of the remainder followed almost of necessity.

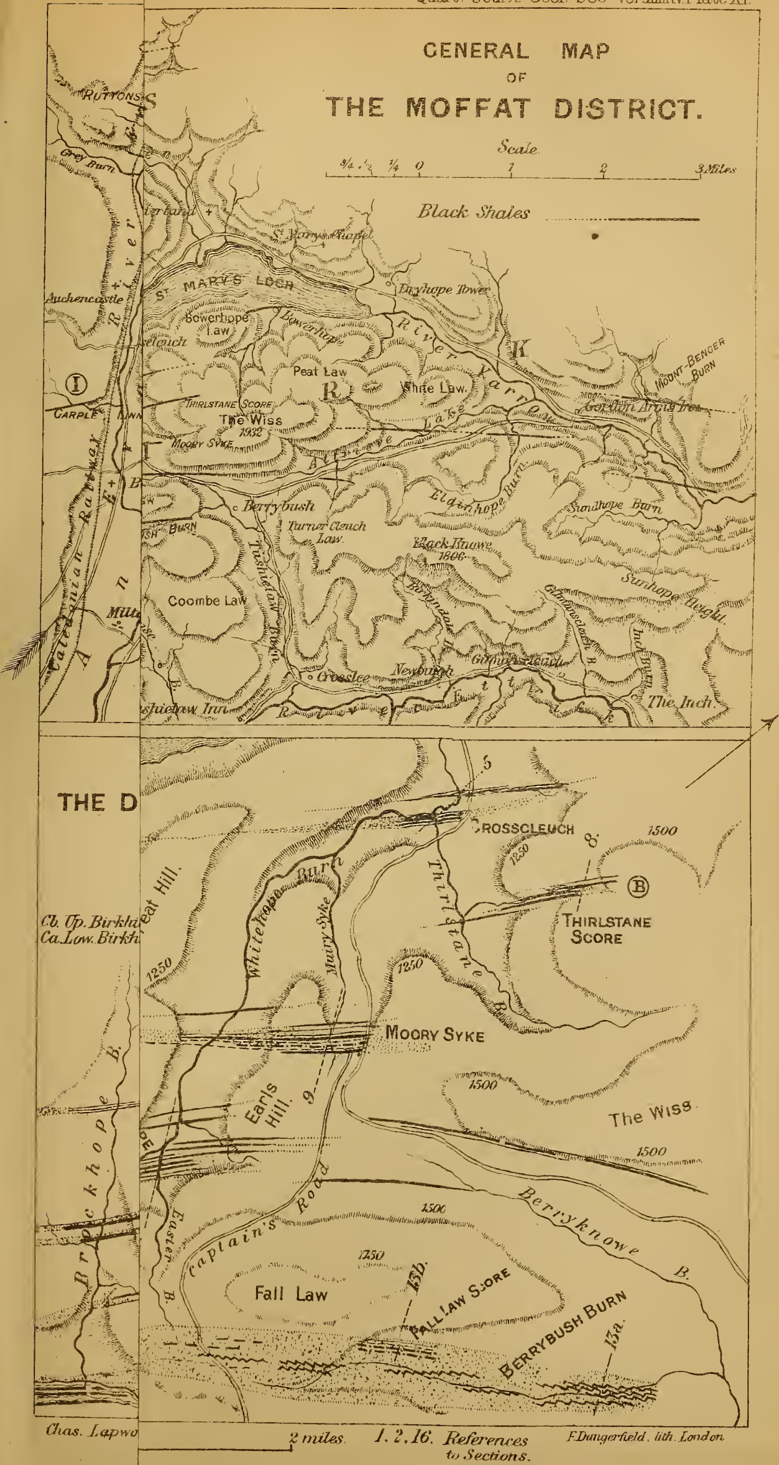
In answer to Prof. Ramsay, the author replied that the general theory of the succession among the South Scottish Silurians adopted by the Scotch Survey was dependent solely upon broad generalizations from the apparent order of superposition, in districts where it is admitted that in any single visible section it is impossible to be certain whether we are ascending or descending in the order of the beds. It leaves all the anomalies of the Scotch beds unexplained, and is crowded with insuperable difficulties. It places in a single subdivision of the Llandeilo formation a thickness of comparatively barren beds almost equal to that of the whole thickness of the fossiliferous Silurian elsewhere. The black beds near the supposed base of this immense formation swarm with Graptolites peculiar to the Llandovery rocks of other countries. Thousands of feet higher in the succession these wholly disappear, and few are met with but peculiar Bala forms; while, at the very summit of the formation, the only survivors are either strictly Llandeilo forms, or have come up from the Arenig itself.

With regard to the two supposed unconformities alluded to, it was admitted by the Professor himself that no physical proofs were forthcoming in support of them. In fact the supporters of this theory have been driven to adopt these breaks in order that they may not be compelled to relinquish their fundamental hypothesis

that there is more than one main band of black shales. The proofs brought forward in the present paper that all the bands of black shale in the Moffat district rise along anticlinal lines render that hypothesis untenable, and rid us at once of the necessity for any unconformity whatever.

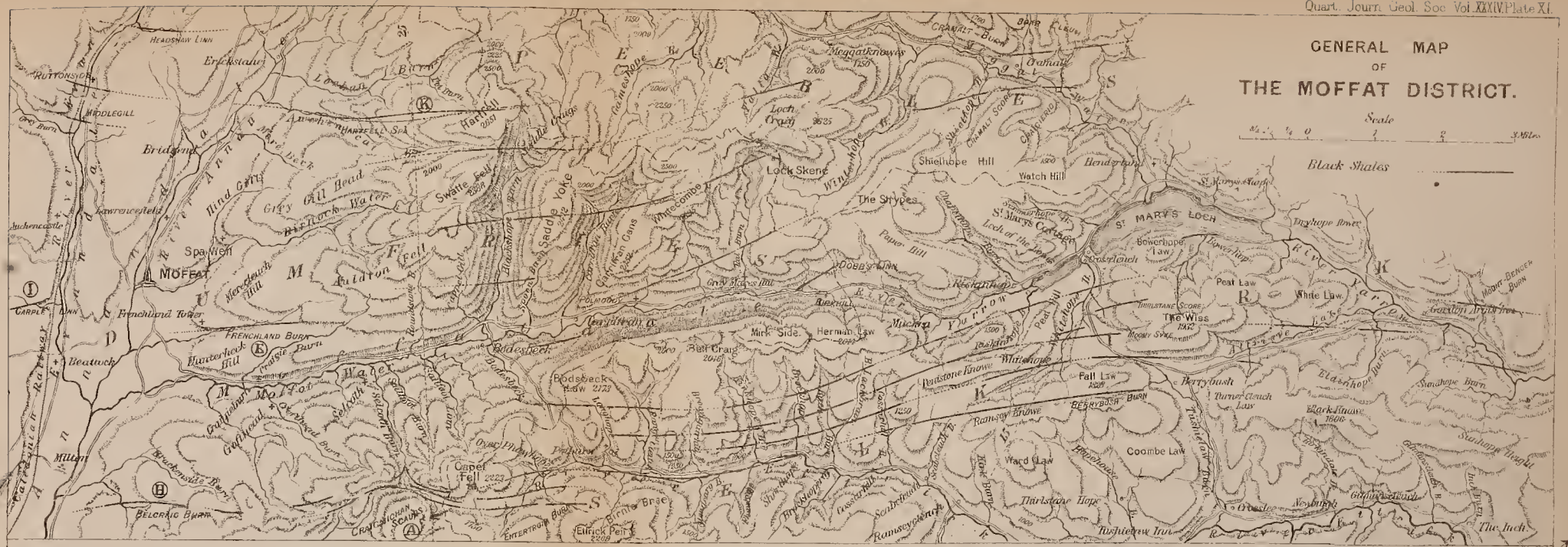
As for the calcareous beds of Girvan &c., which contain, in immediate juxtaposition and apparent intermixture, Brachiopoda &c. elsewhere peculiar to beds of Llandovery, Bala, and Llandeilo age, it was almost certain that towards the N.W. of the southern uplands (as in Sweden, &c.) the black beds are in great part replaced by calcareous rocks, and that we have there a parallel instance of what takes place in the Moffat district, the three distinct Graptolitic faunas of Moffat (whose accidentally intermingled fossils may often be there collected from the talus of a single cliff) being paralleled by the three testaceous faunas of Girvan &c. When it is recollected that in certain localities these shell-bearing rocks are highly conglomeratic, in others involved, shattered, and more or less metamorphosed, it is probable that in some spots many of the forms are derivative, and in others that they owe their apparent intermixture to a variety of accidents.

In answer to Mr. Hicks and Prof. Hughes, the author said that the chief palæontological break in the south of Scotland occurred at the base of the Birkhill shales, *i. e.* between the Bala and Lower Llandovery beds. There is no physical break at this horizon, and the zoological break is apparent only where the Moffat beds are typically developed. Where the Birkhill beds lose their black-shale bands as they pass to the northward, it is impossible to draw a line of demarcation between the Llandoveries, both Upper and Lower Llandovery being probably represented by the greywackes of Peebles and Lanarkshire.


GENERAL MAP
OF
THE MOFFAT DISTRICT.
Scale.
3/4 1/2 1/4 0 1 2 3 Miles
Black Shales
St. Mary's Loch
St. Mary's Chapel
Dryhope Tower
River Yarrow
Mount-Benger Burn
Gordon Arms Inn
Bowerhope Law
Peat Law
White Law
Thirlstane Score
The Wiss
1932
Moory Syke
Carple
Auchencastle
Ruttons
Grey Burn
River Annan
Caledonian Railway
Berrybush
Turner Cleuch Law
Black Knowe
1806
Sundhope Burn
Coombe Law
Crosslee
Newburgh
The Inch
THE D
Cb. Up. Birkh
Ca. Low. Birkh
Crosscleuch
1500
1250
Thirlstane Score
Thirlstane B.
Whitehope Burn
Muiry Syke
Moory Syke
Earls Hill
The Wiss
1500
Berryknowe B.
Captain's Road
Fall Law
Fall Law Score
Berrybush Burn
13a.
13b.
9
8
5
Brockhope B.
Easter B.
Chas. Lapwo
2 miles.
1. 2. 16. References to Sections.
F. Dangerfield, lith. London.

GEOGRAPHICAL DISTRIBUTION OF THE MOFFAT SERIES.

Quart. Journ. Geol. Soc. Vol. XXXIV. Plate XI.



ENLARGED MAP
Shewing
THE DISTRIBUTION OF THE MOFFAT SERIES
TO THE SOUTH-WEST OF
ST MARY'S LOCH.

Ch. Up. Birkhill — Bb. Up. Hartfell ····· Ab. Up. Glenkiln
Ca. Low. Birkhill — Ba. Low. Hartfell - - - Aa. Low. Glenkiln ~~~ W

Chas. Lapworth, Delt. — F. Daingerfield, lith. London.

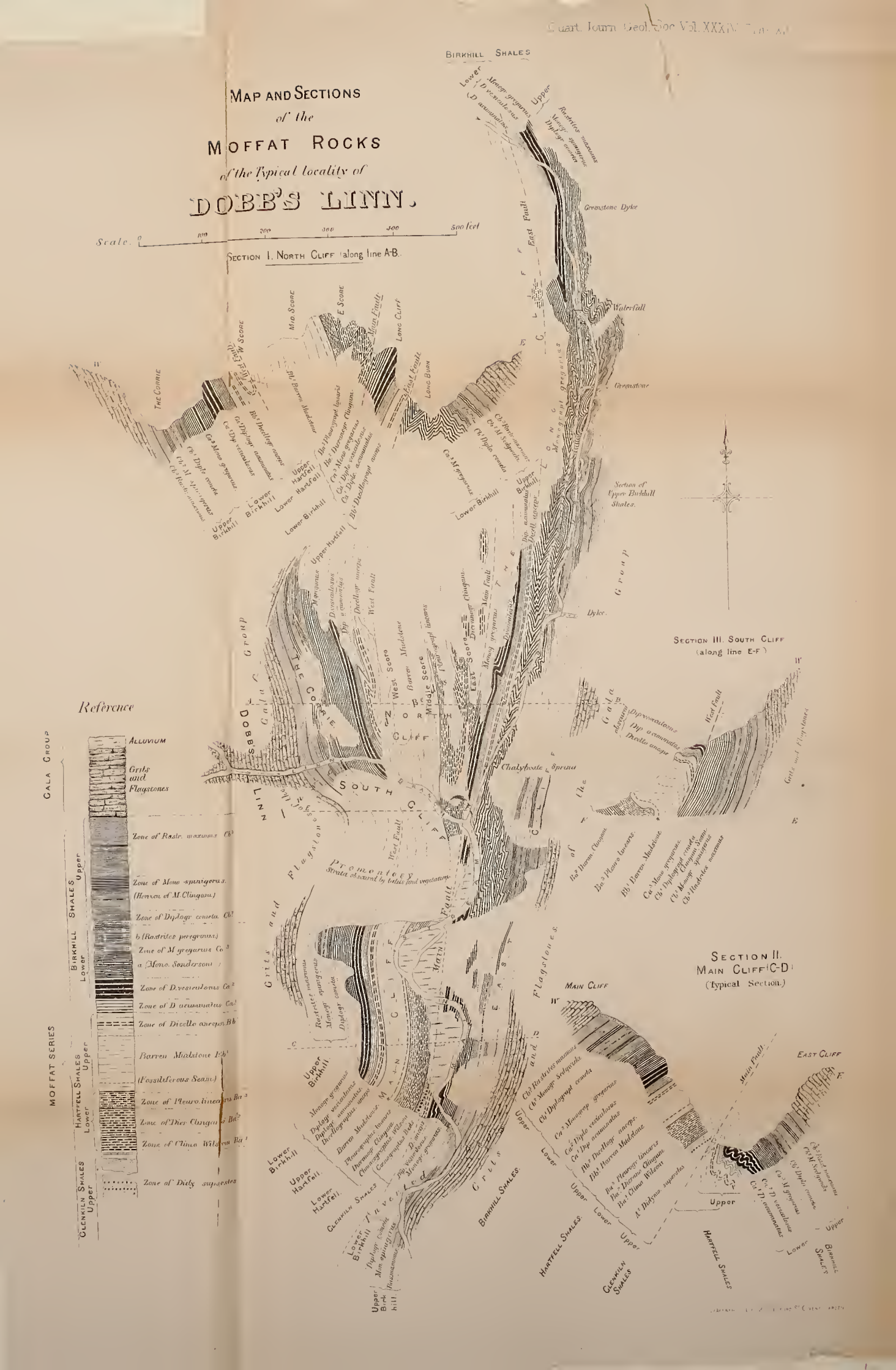
A. C. References to enlarged Plans on Plate XIII

Scale. 3/4 1/2 1/4 0 1 mile 2 miles

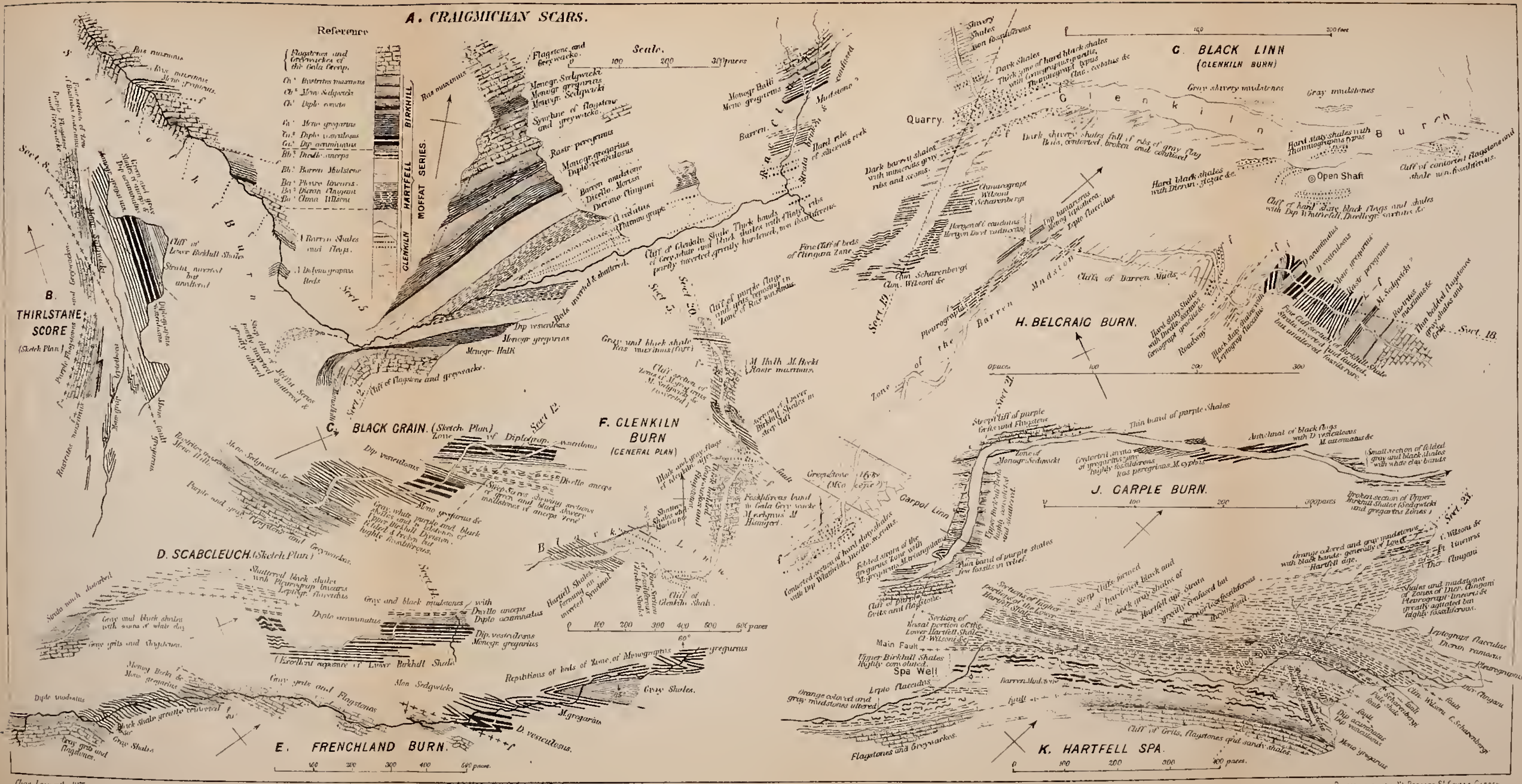
1. 2. 16. References to Sections.


Chalybeate Spring.
the
Gneiss

Map and Sections of the Moffat Rocks of the Typical locality of Dobb's Linn.



PLANS OF THE CHIEF EXPOSURES OF THE MOFFAT SERIES.



Chas. Lapworth 1877.

Dangerfield Lith 22 Bedford St Covent Garden